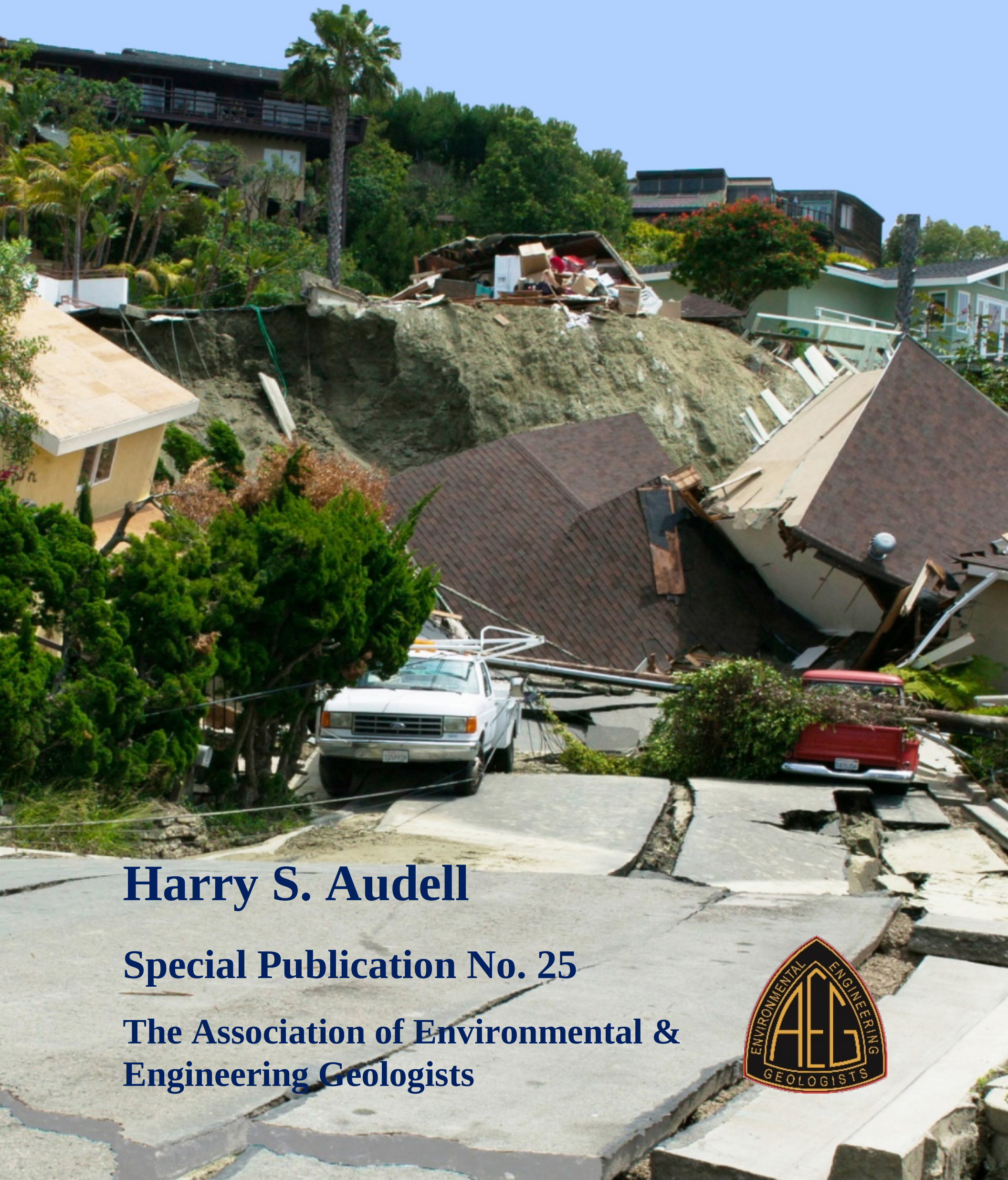
The Residential Geotechnical Evaluation for Ownership Transfer: A Risk Assessment Guideline



Harry S. Audell

Special Publication No. 25

The Association of Environmental & Engineering Geologists

ON THE COVER: Two homes involved in the 2005 Bluebird Canyon Landslide, Laguna Beach, California. This catastrophic, massive translational-type failure destroyed 19 expensive homes, seriously damaged 11 more and no lives were lost. About 1000 people were evacuated from 345 surrounding homes. Photograph by permission, Woodrow Higdon, Geo-Tech Imagery.

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Library of Congress Cataloging-in-Publication Data

Audell, Harry S.
The residential geotechnical evaluation for ownership transfer: A risk assessment guideline
(AEG Special Publication v. 25)
Includes bibliography and index.
1. Geotechnical evaluation, residential 2.Risk assessment
I. Audell, Harry S. II. Association of Environmental & Engineering Geologists III. Series.
1st ed. 2013, ISBN: 978-0-9897253-1-6
2nd ed. 2016

ISBN: 978-0-9897253-6-1

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DEDICATION

This book is dedicated to my late father, Harry S. Audell and late father-in-law, John W. Switack, P.E. (IL). Both were accomplished engineers that have left a deep impression in my career as an Engineering Geologist.

ACKNOWLEDGEMENT

I am particularly grateful to the eminent university professors and private sector professional consultants who have generously given their valuable time to peer-review the first and second editions of this book and provide beneficial suggestions and commentary. Their pertinent publications that specifically address geologic hazards, hazard-structure interaction, and professional practice codes directly influence the everyday performance of the Residential Geotechnical Evaluation for ownership transfer. My method for the assessment of geologic risk builds upon their work, and similar work performed by others. Without their contributions this book would not have been possible. The reviewers for the first (2013) and second edition* (2016) are listed in alphabetical order:

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Also, I thank Dr. William Smith (AEG Special Publication Manager) for coordinating the reviewers and acceptance of the second edition manuscript for publication. Finally, I thank my wife, Margaret S. Audell, M.D., for her unyielding encouragement, patience and support in seeing this project to completion.

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FOREWORD

The purchase of a home is perhaps the largest financial commitment most people will make during their lifetime. The assessment of a property's "geologic risk" is one of many aspects of the purchase, and is of significant concern to the homebuyer. For this reason, the homebuyer may request a **Residential Geotechnical Evaluation (RGE)**, which provides them with information critical to their decision. Although guidelines have been proposed, neither the geotechnical industry nor academia has yet to establish a "risk" assessment guideline for professional engineering geologists and geotechnical engineers (i.e. practitioners) to follow when performing a RGE. This publication is intended to help fill that void.

Typically, a home buyer's initial introduction to the RGE begins with the purchase of a developed property through a Realtor®. Most home sales and purchases in the U.S. are regulated by state laws and a Board of Realtors®. At least thirty-two states have formal seller disclosure requirements and the Board of Realtors® of each state uses standardized contracts for all transactions. Home buyers are given the option to perform a due diligence RGE prior to the closure of escrow. After learning of a seller's disclosure, a home buyer will typically contact a practitioner and inquire about an RGE.

There is wide variation in the services and information provided by practitioners who perform the RGE, and the public is often confused as to what they should expect. As a result, they question the value of the RGE and often purchase a property without one.

This guideline establishes baseline procedures and prioritizes the essential elements of a conclusion statement issued as part of the RGE. The determination of geologic risk is the final element of the conclusion statement and provides the "bottom line" for the study. Preliminary risk-management recommendations are then proposed for addressing improvements or repairs.

The advantages of an RGE are obvious. Not only does the public benefit from a comprehensive RGE performed by professionals who understand the complicated aspects of hazard-structure interactions, but practitioners also benefit from reduced liability exposure by conforming to generally accepted guidelines. In addition, it eliminates the buyer's negative perception of potential conflicts of interest that often accompany these studies. A standard guideline provides transparency and comforts buyers in knowing that they are receiving an unbiased and objective opinion.

The status quo in the performance of the RGE necessitates improvement. The author feels that the industry should recognize some minimum standards. Since standardized methods of testing and analysis abound in the geotechnical field, it is appropriate that one should be devised and followed. The author hopes that this effort will compel practitioners to utilize the most current scientific methodologies of academia and industry.

PREFACE

In response to California legislation pertaining to the sale of residential real estate, the geotechnical industry began performing RGE's in 1984. This is the area where I have focused my eneregies for the majority of my professional career.

As a professional engineering geologist, I have specialized in the forensic application of the RGE for home buyers, sellers, lenders, insurers and attorneys. I have performed thousands of RGE's in the southern California area over the last 35 years, and have participated in many legal cases as an expert witness.

Throughout my career, I have published several professional papers through the Association of Environmental & Engineering Geologists (AEG) in an attempt to introduce field procedures, analytical methods, and conclusion statements for the RGE. The development of this guideline is contained in my previous publications (see References Cited).

This book refines my prior publications, and as a result, it is the first inclusive document for performing an RGE. It is not the final statement on this subject, but rather a minimum basis that may be built upon by other geotechnical professionals. With further improvement, and public awareness, the RGE may become commonplace in all real estate transactions.

The presumption that the geotechnical community will immediately embrace this guideline is premature. As with any new method, it requires testing and verification before being accepted by professional engineering geologists and geotechnical engineers. Therefore, it is expected that questions may arise. However, I have used this guideline successfully and have found it scientifically sound for evaluating near-term geologic risk.

To fully comprehend the RGE methodology, prerequisite reading of "The Allowable Settlements of Buildings" by Skempton and MacDonald (1956) and "Field Guide to Crack Patterns in Buildings" by Audell (2006) are recommended. In addition, a strong knowledge of hazard-structure interaction processes and an understanding of building distortion indicators are necessary. Lastly, a sufficient amount of training and experience is required before assisting homebuyers in making the most important financial decision of their lives.

All aspects for performing a RGE are discussed in this book. Provided are numerous figures and tables for clarification. With this latest edition (2016) one section has been added and other sections have been expanded to provide depth and clarification to the understanding and performance of the RGE. The first chapter introduces background information which includes: The need for a guideline; how a northern California lawsuit, *Easton v. Strassburger, et al*., established legal precedents and laws; the definition of real-time geologic risk; modern home construction and the RGE guideline theory. This chapter also gives recognition to previous workers who have authored publications on related subjects from which this guideline was derived. Chapter 2 delves into the differences between the "inspection" and "evaluation," and the three tiers of RGE's. Chapter 3 presents the guideline, which consists of a five-part assessment and also presents a conclusion statement that should accompany various tiers of evaluations. This chapter also provides an example RGE. Chapter 4 discusses risk management as applied to residential properties. Chapter 5 focuses on certainty and confidence and the factors that influence the accuracy of the RGE. Chapter 6 discusses common liability pitfalls in performing an RGE. Chapter 7 points out field applications and evaluation of geologic and engineering data to develop objective conclusions. Chapter 8 presents an RGE case history of a property involved in two disclosure lawsuits tried in Superior Court of California, Orange County. Chapter 9 summarizes the text, the benefits of the RGE, and the professionals that may find the RGE useful in their practice. A list of the references reviewed is presented in the References, definitions of terms used are provided in a Glossary of Terms and acronyms and symbols are indicated in the Abbreviations. Appendix A provides an abridged assessment guideline format for preparing a RGE report. Finally, all photographs are by the author, unless otherwise noted.

Any questions, comments, or criticisms by the professional community are welcome and will be addressed in following editions.

Harry S. Audell, P.G., C.E.G.
June 2016

The Residential Geotechnical Evaluation for Ownership Transfer: A Risk Assessment Guideline

Harry S. Audell

1
INTRODUCTION

Background

The Residential Geotechnical Evaluation (RGE) is a geotechnical study that assesses the "geologic risk" of a residential property. Understanding risk has relevance to forecasting a geologic hazard, assessing a building's safety for occupancy, and determining its monetary value. Homebuyers, home sellers, loan and insurance companies consider risk in their decision making. The RGE facilitates a rapid risk assessment of most types of residential buildings founded on lots with various site conditions.

As early as 1954, J.T. McGill reported of performing residential geologic examinations for homebuyers, and provided a checklist for recognizing building-site problems that cause property damage (McGill, 1954). Also, Brown (1984) discussed performing foundation inspections and evaluations for the residential buyer and provided a checklist for this work. Further, the author (Audell, 1992) had presented a checklist and disclaimer for performing the RGE. Unfortunately, no formal guideline or recommendations have been adopted to govern the scope of RGE's by industry professionals, even though some have expressed the need for "…common standards…and to begin publishing guidelines…" for this type of work (Olshansky and Rogers, 1992). For an overview of professional practice guidelines, see Brown and Proctor (1985).

This publication provides the professional engineering geologist and geotechnical engineer (practitioner) with an assessment method that elevates the typical (status quo) study to a practical evaluation. It explains the complicated relationships of natural geologic processes and hazards, their impact on buildings, a hazard's rate of ground activity, and consequent risk to residential properties. In addition, specific risk response and management options are proposed to assist a home buyer in estimating the likely costs of repair or suitable mitigation. The RGE conclusion statement permits the homebuyer to make informed decisions before the purchase of a property. Also, the method of the RGE can be repeated and the results verified by other workers examining the same property.

The RGE is typically performed for home buyers, home sellers, and homeowners. However, it is the home buyer who receives the greatest benefit from this evaluation. Most often the home buyer is unaware of the importance of a geotechnical assessment prior to the purchase. Even a home buyer who elects to have the assessment performed is often confused as to what to expect from their consultant. Perhaps less than ten percent of all properties sold receive an RGE prior to closure of escrow. The public's perception of homes sold with ground movement problems is evident even in popular newspaper comic strips, Figure 1.

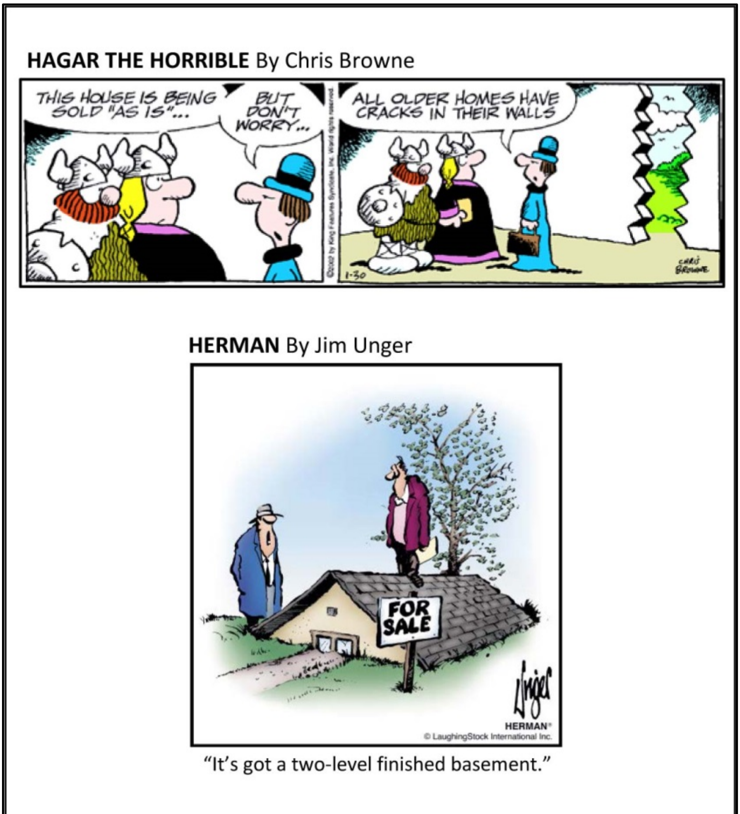


Figure 1. Two popular comics that reflect the public's perception of homes sold with ground movement problems. Both are reprinted with permission.

Application

The RGE can be performed on the majority of tract and custom built residential structures less than 50 years in age, of any size or shape, and situated in various geologic settings. It can be applied in most regions throughout the country, or modified to suit particular locations that are unusual.

The RGE is intended for light- and heavy-framed constructed residential buildings that typically employ conventional shallow foundation systems, such as slab-on-grade with continuous perimeter footings, raised floor with continuous strip and intermediate post-and-pier supports, post-tensioned slab and basement retaining/stem wall and slab floor types.

It is most applicable in active (high energy or seismic) geographic regions with numerous life-threatening geologic hazards. This includes mountain regions, such as the West (Pacific and Mountain) and Northeast (Middle Atlantic and New England). It will be useful in other states with a seismic element, including AR, MO IL, KY, TN, and SC. However, regions east of the Rocky Mountains, such as the South and Midwest that are low-energy or aseismic may find less application. This pertains to geographic zones bereft of life-threatening hazards that could render a building "unsafe for occupancy." Further, not discussed are climatic factors, such as wind, rain, and snow, or environmental factors, such as soil or mold contamination that can also threaten a building's safety for occupancy.

The RGE may be limited in its application to atypical residential structures or extreme/unusual geotechnical conditions. These exceptions may include buildings using specialty ridged foundations, such as pier, mat or raft types or buildings located in unstable geologic settings, such as landslide or karst (sinkhole) terrain. In these cases the RGE can be modified, however, the basic tenets of the guideline remain unchanged.

Performance of the RGE, as presented here, is not a code requirement or currently a standard-of-practice, however, may be considered a standard-of-care. It is performed at the discretion of the practitioner or at the requirement of a knowledgeable homebuyer. Because the RGE is a contiguous systematic method, use of individual or extracted parts is strongly discouraged because it may misdiagnose geologic risk. The suitability of the RGE to the region, building and lot under evaluation is determined by the practitioner. Only over time, as the RGE gains acceptance by many industry professionals may it be considered a protocol and standard-of-practice for performing this work for the public.

Legal Precedent

This guideline was created in part as a specific response to a California lawsuit, *Easton v. Strassburger*, and the subsequent law, titled the California Real Estate Disclosure Law. This landmark case, filed in 1976 in the Superior Court of California, Contra Costa County, was the result of a nondisclosure sale of a property with known ground movement issues and related building damage. The jury found in favor of the plaintiff, Easton. Strassburger later filed an appeal in the California Court of Appeals in 1984. The lower court verdict was upheld in favor of Easton. A subsequent petition for hearing was filed by Strassburger in the Supreme Court of California, but was denied.

The California Legislature passed the Real Estate Disclosure Law (Civil Code 1102-1102.18) on May 31, 1984. This lawsuit established the legal precedent for seller and Realtor® disclosure in real estate transactions.

In disclosure states, home sellers and listing agents are required by law to provide information of the geologic, structural and environmental conditions of the property. The states that have disclosure laws are (by postal abbreviation): AK, AZ, CA, CT, DE, GA, HI, ID, IL, IN, IA, KY, ME, MD, MI, MS, NE, NV, NH, NY, NC, OH, OK, OR, PA, RI, SD, TN, TX, VA, WA and WI. The laws of each state may vary because of specific local issues. The Board of Realtors® of any state can provide information regarding seller disclosure responsibilities.

Definition of Geologic Process, Hazard and Risk

Understanding the methodology of the RGE necessitates clarification of the terms geologic "process," "hazard" and "risk" because they have been used throughout the literature in various contexts that, in some cases, are contradictory from one work to another. Here, the terms process and hazard have congruent definitions that unifies the meaning of geologic risk.

The term "geologic risk" has a wide variety of definitions, but is often used in the context of a potential occurrence of a natural event. It is often referred to, and widely accepted as, the vulnerability of a structure to become damaged because of a potential natural hazard (Varnes, 1984; and OAS, et al.

1991). Varnes' definition of variables and equation for determining potential risk is presented in Figure 2.

DEFINITION OF GEOLOGIC RISK*

Definition: The vulnerability of damage to a structure due to a potential natural hazard.

Natural hazard (H) means the probability of occurrence within a specified period of time within a given area of a potentially damaging phenomenon.

Vulnerability (V) means the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. It is expressed on a scale from 0 (no damage) to 1 (total loss).

Specific risk (R_s) means the expected degree of loss due to a particular natural phenomenon. It may be expressed by the product of *H* times *V*.

Elements at risk (E) means the population, properties, economic activities, including public services, etc., at risk in a given area.

Total risk (R_t) means the expected number of lives lost, persons injured,damage to property, or disruption of economic activity due to a particular natural phenomenon, and is therefore the product of specific risk (R_S) and elements at risk (*E*).

Thus: $R_t = (E)\,(R_S) = (E)\,(H \times V)$

Ref: After Varnes (1984)
*Per RGE, this definition pertains to pre-hazard risk.

Figure 2. The definition of geologic risk according to Varnes (1984).

Varnes (1984) introduces some confusion with his mixed usage of the terminology “potential natural hazard” that detracts from the important distinction of the terms geologic “process” and “hazard.” As used here, the potential occurrence of a natural condition, or the occurrence of a condition that affects neither life, structures nor real property, is termed a “process.” A process becomes a “hazard” should the condition affect life, structures or real property. Further, as applied to two neighboring properties, what is a hazard on one may be a process to the other. Varnes’ definition and equation is recognized as a viable method for determining “vulnerability of damage to a structure” from a geologic process (before it occurs). While Varnes’ method for qualifying risk may be useful in a regional sense, it is impractical for the RGE because the evaluation of a property is real-time and site specific.

In the first edition of this book (2013) I claimed that, “risk is not exclusive to potential hazard occurrence, but also includes an existing hazard, which has consequent risk as well.” To elaborate this premise, I present new theory to advance the definition of geologic risk as applied to the RGE.

The dynamics of ground movement and its effect on buildings progresses in stages. Five stages are identified and shown below on a process flowline, Pf. (1):

Pf. (1): *Potential process* → *process* → *hazard* → *building impact* → *building failure*

This sequence of stages, I shall name the Process-Failure Progression. Each stage represents the geologic condition as it transitions from the on-set of a process to building failure relative to its rate of ground activity and its impact on the building. The boundaries between each stage can be clearly identified throughout the progression in real-life situations. Ground movement, derived from a hazard, is a function of time, and may increase or decrease in activity. Geologic impact to the building is time independent. Further, the extent of geologic impact to a building can be identified at the time of the assessment, and can be forecasted for future impact if the hazard is allowed to persist. Any building deemed unsafe for occupancy is considered a failed building. The Process-Failure Progression can be initiated naturally or by man.

Geologic risk is derived from the Process-Failure Progression. Risk proceeds continuously as phases that are in parallel with the Process-Failure Progression. Three phases are identified and are shown below on a process flowline, Pf. (2):

Pf. (2): *Pre-hazard risk → post-hazard risk → termination of risk*

This sequence of phases, I shall name the "Risk Continuum." Risk is time dependent because it is ground activity that drives the continuum. It can increase or decrease depending on the hazard's rate of ground activity. Further, it is acquired, and presents an exposure and measurable expectancy based on the hazard impacting a building. The extent of risk can also be correlated with the aggressive nature of the hazard. Two flowcharts correlating the stages of the

Process-Failure Progression and the phases of the Risk Continuum are shown in Figure 3.

Therefore, with this correlation, the three phases of risk are elaborated: 1) Pre-hazard phase- representing the potential occurrence of a process and/or the actual occurrence of a process without impact to a building, 2) Post-hazard phase- representing the transition of a process into a hazard, and expectancy for continued and increased impact to a building from a hazard. “Ultimate risk” is realized just prior to building failure, and 3) Termination phase- representing the point of initial building failure. A “Risk Expectancy Scale” is presented herein for determining the score of geologic risk at that point in time the assessment is conducted.

The determination of the phase of risk is a key element to the proper performance of the RGE. The phase determination depicts a building’s safety for occupancy, as well as its likely value, desirability, and demand. Furthermore, it is the post-hazard risk that is of most interest to a home buyer when considering a residential property purchase. An equation for the quantitative calculation for the phases of risk has not yet been developed. However, graphic solutions for the qualitative analysis and determination for post- hazard geologic risk are presented.

Most laymen connote the term “risk” as a prediction of a geological event with consequent damage. This understanding is incorrect because risk cannot be predicted with any meaningful accuracy. It can only be forecasted. Some processes, such as earthquakes and landslides, defy prediction. However, post-hazard risk can be forecast with some measure of certainty and confidence, depending on available infor-

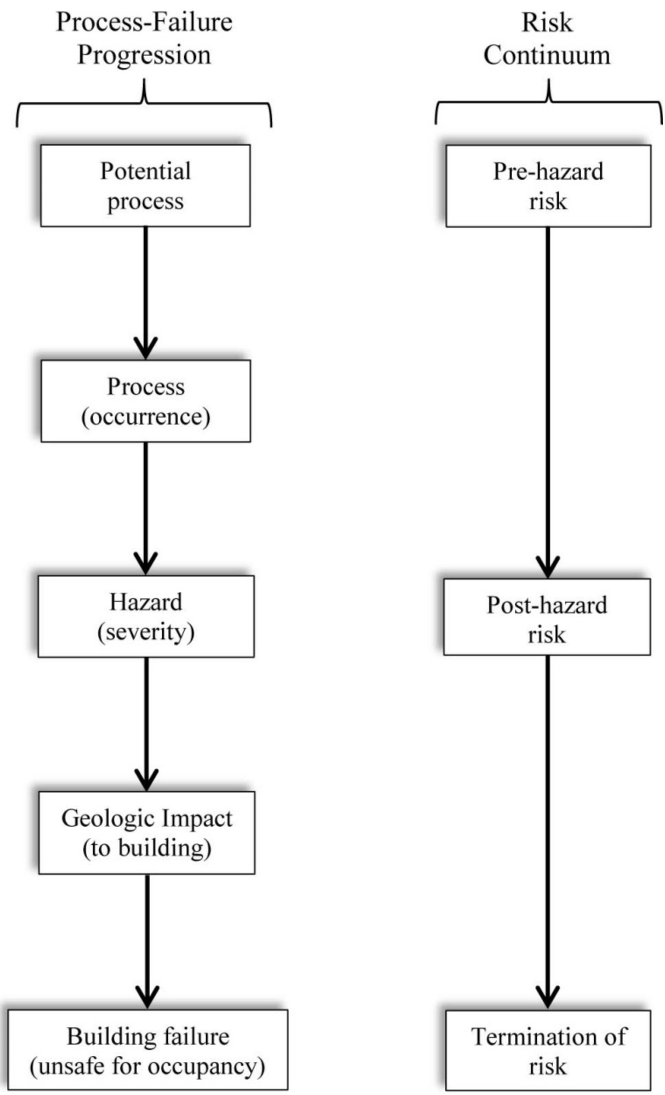


Figure 3. Correlation of the Process-Failure Progression and the Risk Continuum flowcharts.

mation and its accuracy. It is post-hazard risk that is most useful when making rapid and educated decisions.

The RGE is a real-time assessment. If impact and ground activity are identified in the field, then real-time risk from a hazard may be immediately evaluated and communicated to the home buyer. An RGE that omits a discussion of real-time, post-hazard risk may, therefore, be inconclusive and of no value.

Modern Residential Buildings

Over the decades the construction quality of houses has undergone numerous improvements because of the involvement and contributions from academia, industry, professional societies and associations, and government organizations. These include: universities, the American Society of Civil Engineers (ASCE), the Association of Environmental & Engineering Geologists (AEG), the U.S. Geological Survey (USGS), state geological surveys, International Council of Building Officials (ICBO), and the American Society for Testing and Materials (ASTM), just to name a few. However, specific to house stability from a geotechnical and structural engineering standpoint, the significant design and construction improvements of modern residential construction can be shown. The inclusion of Chapter 70 (Excavation and Grading Code) in 1964 into the Uniform Building Code (UBC) established design requirements for site grading, and identified engineers and geologists responsible for design, construction monitoring and approval of such work. The ASTM established testing methods and material standards for rock, soil, lumber, concrete and steel, and their application to geotechnical and structural design, site grading and construction. By the early 1970's the advancements of the science of engineering geology and its application to civil engineering works was embraced by the building industry. As a result, houses became better built, lasted longer and are safer to occupy.

Later, as industry applied advancements in science and technology to design and construction, any encountered problematic geologic issues (hazards) had established geotechnical engineering solutions. Foundation systems improved and the rigid post-tension slab foundation debuted in the middle to late 1970's. Further, following several catastrophic earthquakes in California, particularly the 7.2M, 1989 Loma Prieta earthquake during which 63 people perished the seismic design of a house's superstructure shifted from a "sway" to a "stiff" performance philosophy. The 1991 UBC required the wrapping of the house's exterior framework with plywood sheeting, and use of steel moment-frames to increase superstructure stiffness. Probably the 1991 UBC, which encompassed all of the latest advancements in building design to date, represents the new era of modern house design and construction. Of course, much advancement has been made since, but the greatest improvements are indicated above.

All of these improvements have, in some respect, made diagnosing the structural behavior of the modern house more complicated because of the decreased expression of evident strain indicators. The modern wood-framed house supported on a post-tensioned foundation will perform better when subjected to seismic horizontal loading (earthquakes) and aseismic vertical ground movements, such as subsidence or heave from expansive soils. In particular, the post-tension slab foundation may still undergo deflection, but the occurrence of slab cracks is minimized. As well, the plywood-clad superstructure will resist distortion resulting in decreased cracking in walls and ceilings, bowed walls, and out-of-square door frames. For buildings of low and moderate geologic impact these indicators are infrequent or subdued, however, for buildings of high to unallowable geologic impact they become more evident. Where indicator evidence is lacking, greater emphasis should be placed on the floor level survey data that demonstrates the extent of foundation deflection, which is the best indicator depicting geologic impact. Human intervention may also complicate the diagnosis by obscuring indicators, such as by homeowner patching and painting, or the remodeling of a house. The practitioner should utilize whatever reasonable, noninvasive methods necessary to discover the true extent of geologic impact to the modern building.

The Assessment Guideline

This assessment guideline is presented to facilitate the rapid determination of post-hazard geologic risk. Risk is the final element of a five-part conclusion statement. It is founded upon the geotechnical theory of hazard-induced impacts to buildings. The following discussion is a modified reiteration of my previously presented papers which address this topic.

The guideline's fundamental premise is that the earth's dynamic surface creates a variety of naturally occurring geologic processes. These processes become hazards only if or when they impact (distort) structures or appurtenant property improvements. Geologic impact is represented by diagnostic primary and secondary strain indicators. The dimension of these indicators, when compared to an allowable limit, determines impact, and when compared to the age of certain building elements, determines the apparent rate of ground activity. The relationship between impact and ground activity determines real-time post-hazard geologic risk. Hazard mitigation can serve to effectively reduce ground activity, which minimizes real-time risk to a building.

Qualified Practitioners

Any person possessing a state issued license as a professional geologist (PG) or professional engineer (PE) (i.e., civil or structural) is qualified to perform the RGE. In many states, only the PG and PE (civil or structural) license is recognized, but some states distinguish specialty licenses such as the certified engineering geologist (CEG), geotechnical and geological engineer (RGE) expertise. It is these professionals that are typically best suited to perform the RGE. Because these specialties comprise this profession they are similar, yet there are some distinctions. As delineated in the Engineering and Geology Practice Guidelines (JTFAP, 2009) the geologist specifies the nature of the geological processes, hazards and impacts on the built environment, whereas the engineer deals with the design relationships pertaining to soil-structure interactions. Dybel (2015) further expands the qualification of the practitioner to include the following: 1) Have extensive knowledge of the geologic conditions in the geographic area; 2) Have knowledge of the history of building design and performance criteria, local building code changes, and standards of practice; 3) Have knowledge of geologic processes that are capable of causing damage; and 4) Have an open mind. As for the RGE, the determination of geologic risk is not exclusive to one or the other discipline. A home buyer hiring more than one of these professionals is impractical for two reasons: first the cost, and second the continuity of the rendered opinions. Therefore, the engineering geologist, geotechnical and geological engineer are assumed to be knowledgeable and experienced in each other's discipline.

Previous Workers

Research was performed to locate academic and professional publications that deal with geologic hazards related to ground movement, the consequent distortion to buildings, and risk assessment. The literature reviewed is presented in the References.

There are multitudes of publications that deal with ground movement and/or building distress, too many to include all for this narrow subject of study. The selection process was difficult, but only those papers addressing specific aspects relative to the RGE were reviewed.

Of the referenced papers included here, many are well recognized in the profession and depict the geotechnical concerns of ground movement induced building distortion. Some referenced papers also identify threshold limits for building distortion. Unfortunately, none of these publications set forth the important relationship between geologic impact to the building and ground activity as the key elements in assessing real-time, post-hazard geologic risk.

2

TYPES OF GEOTECHNICAL EVALUATIONS

Inspections and Evaluations

There are two types of geotechnical property studies: 1) the inspection, and 2) the evaluation. These are different. In general, the inspection identifies the hazards and non-hazard conditions that account for building distortion. However, the evaluation (which includes the inspection) interprets the relationship between the hazard and impact, and renders a risk assessment.

Many practitioners who perform the RGE often confuse an inspection with an evaluation. Simply reporting the geologic conditions of a property and distress within the building does not constitute an evaluation. These reports are easily identified because they lack an analytical assessment for geologic impact, ground activity and risk.

The inspection process entails collection of data that pertains to the condition of the structure and lot. This includes research of the available geotechnical reports and maps, the identification of the potential processes that could affect the property, the existing hazards affecting the building, and the documentation of the impact indicators within the building.

The evaluation process builds on the data gathered from the inspection. It provides a calculated comparative analysis used to derive the conclusion statement. The analysis, which is a geotechnical interpretation of the data, yields three important aspects of the conclusion statement. These are: The category of impact to the building, the rate of ground activity, and the level of post-hazard risk to the building. A detailed account for the determination of risk is given in Chapter 3.

RGE Tiers

The RGE has three tiers. Each fulfills a role for the home buyer, seller, lender, insurer or attorney. These tiers are distinguished by an increasingly comprehensive scope of work and corresponding levels of expense. Evaluations should employ the same analytical procedures to standardize the assessment for risk. Certainty and confidence is improved as each study becomes more inclusive. The tiers of RGE's are:

- Tier I-Empirical evaluation
- Tier II-Qualitative evaluation, and
- Tier III-Quantitative evaluation

Tier I-Empirical Evaluation

The Tier I empirical RGE is a generalized verbal walk-through consultation with the home buyer. It relies primarily upon the practitioner's experience and knowledge of local geologic settings, types of residential buildings and their period of construction. This is the minimum level of evaluation. Its advantages are: It provides an on-site verbal summary to the perspective home buyer, a rapid assessment of the property requiring no post-field work reporting, and is the least expensive. For these reasons, it is the most popular with home buyers. The scope-of-work typically includes:

- Research of readily available geotechnical reports and maps (e.g., state geological survey, USGS geologic and topographic maps, aerial photographs) pertaining to the site and relevant information from other public sources,

- An interview with the home seller, or representing listing Realtor®, to obtain salient information regarding disclosures of hidden conditions,
- Site visit to observe, measure and record the visible geotechnical conditions of the lot and the geologic impact indicators (primary and secondary) readily observed within the building,
- Performance of a detailed floor level survey (e.g., by manometer or auto-leveling laser level),
- A comparative qualitative analysis of the data, and
- Verbal presentation of the observations, findings and conclusions with recommendations.

As a consultation-based study, its disadvantages are: It carries the highest level of liability to all parties because no written report is provided to the home buyer; the home buyer is required to take notes during the consultation; certainty and confidence is usually moderate (which depends upon the immediate availability of observable indicators); and the buyer must remember the information.

Tier II-Qualitative Evaluation

The Tier II qualitative RGE is more extensive than the empirical evaluation. Its advantages are: There is an increase in certainty and confidence; additional research is performed; and liability exposure is decreased because a report is prepared. This study would be desirable for a homebuyer, seller, lender or insurer. The scope of work includes that indicated in the Tier I study plus:

- Research at the local municipal agency of the building and grading files,
- Report preparation using the RGE Guideline, and presentation of the conclusion statement with recommendations.

This qualitative study has a few disadvantages: It is more costly to the home buyer; and it could take a few days to complete. Geotechnical reports can take different forms, such as a checklist or full report types. The checklist format has been popular for years (McGill, 1954 and Audell, 1992) and is preferred by homebuyers, whereas the full report is required by sellers or a bank.

Tier III-Quantitative Evaluation

The Tier III quantitative RGE (or investigation) is the most rigorous of the studies. Its advantages are: It involves more research; it is the most informative because of its depth; it provides the highest level of certainty and confidence; and it carries the least amount of liability. It is typically performed on properties where the damage to buildings and site improvements is obvious, extensive, and/or uncontested. It is seldom performed for home buyers and sellers, but is frequently requested by insurance companies for claim resolution and attorneys presenting a disclosure lawsuit. The scope of work includes that indicated in the Tier II study plus:

- Background research of papers published in professional journals that may pertain to the area or that specifically address new observations, findings, and conclusions,
- Site-specific subsurface exploration using drilling equipment and sampling of soil and rock units,
- Laboratory testing of collected samples,
- Performance of a manometer floor level survey,
- A comparative quantitative analysis of the data,
- Detailed report preparation using the RGE Guideline, and presentation of conclusion statements with recommendations.

The quantitative level of study has several disadvantages: The mobilization of heavy drilling or trenching equipment on the property; the labor required to organize and execute the investigation; the length of time to complete the investigation and generate a report; and its inherently high cost. Typically, both engineering geologists and geotechnical engineers would be involved in the investigation.

Buyer Responsibility

It is the home buyer (or client) who ultimately chooses which tier of RGE the practitioner performs. Considerations are usually given to cost-benefit, the level of certainty and confidence of the RGE conclusions, and protection of the personal financial commitment associated with the property purchase. The practitioner is to provide a recommendation to the client of which tier of RGE is most appropriate depending on the use and intent of the study; however, it is the client who accepts the financial responsibility for the type of study performed, the usefulness of the information provided, and the final decision regarding purchase.

Estimating Damages

The engineering geologist, geotechnical or geological engineer is qualified to provide a preliminary estimate of repair for observed damages to a building or lot. This is often referred to as an "Engineer's Estimate." The homebuyer may require this information for decision making. However, caution is forewarned especially if the homebuyer's decision is predicated on the estimated cost of repair.

Estimating requires specific knowledge of the geotechnical conditions of the lot and the structural conditions of the building. Whether verbalized or written, estimates can vary widely and depend on the type of repair, design recommendations, material cost and availability, labor costs and manpower, and unknown subsurface conditions. Bereft of these details an inaccurate estimate will only serve to mislead the homebuyer. A Tier I or II level of study may not derive the quality or quantity of data necessary to opine an estimate. In these situations the practitioner should decline to provide an estimate and recommend that a Tier III investigation be performed for design purposes, a Licensed Contractor become involved, and estimates from other parties be obtained. Typically, preliminary estimates vary considerably from the actual costs of repair.

3

THE ASSESSMENT GUIDELINE

<u>Introduction</u>

This guideline consists of a five-part, systematic hazard-impact-risk assessment that comprises the core of the RGE. It is performance-based, typically site specific and governed by the behavior of buildings and site improvements on the property. Specific aspects of each part are explained below. A conclusion statement is derived for each property examined. The conclusion statement is shown in Figure 4.

> The guideline elements that constitute the conclusion statement for the RGE are:
>
> - Geologic processes that could affect the building and the lot,
> - Geologic hazards that currently affect the building and the lot,
> - Category of real-time geologic impact to the building,
> - Rate of real-time ground activity from the hazard(s) affecting the building, and
> - Score of risk expectancy (RES) for a hazard(s) to impose additional impact to the building.
>
> Ref: Modified from Audell (1992 and 1997)

Figure 4. The guideline elements of the conclusion statement.

Part 1- Geologic Processes

Geologic processes fall into two main categories, 1) the potential for occurrence of a natural condition, and 2) an existing condition that neither effects life, structures nor real property. Processes of either category have pre-hazard risk potential. The pre-hazard risk potential for any process can be empirically and qualitatively evaluated for their possible and anticipated impact to life, structures and real property. This has been demonstrated in planning scenarios for evaluating the potential for earthquake and landslide occurrence and their anticipated impact to communities, but can also be applied to existing geologic processes that could become hazards and danger or encroach upon human activities. For the pre-hazard risk potential determination to possess a high level of certainty and confidence the critical geotechnical factors relating to their occurrence, or their presumed encroachment on human activities, must be known.

The geologic setting of a property refers to the types of natural processes and their propensity for occurrence. Several factors define their character. These are: Their type, propensity for occurrence, state of ground activity, and causation and triggering mechanisms. Two general types are recognized: Naturally occurring and human-induced. Their occurrence potential varies depending upon specific natural conditions or human-made features and triggering mechanisms. They are also classified based upon their state of ground activity. Dynamic processes are constantly in an active state of ground movement, whereas, transient processes exert a temporary state of ground movement. Some processes can have dynamic and transient attributes. All processes are attributed to a cause and trigger mechanism. The relationships of natural, human-induced, dynamic and transient processes are shown in Table 1.

Table 1. The types of natural and human-induced geologic processes. Connector line between dots indicates either/or type of event.

NATURAL PROCESSES	TYPES		
	Human-induced	Dynamic	Transient
Chemical corrosion		●	
Earthquake shaking			●
Erosion	●		●
Expansive clays	●	●	
Fault rupture/creep		●—	—●
Ground rupture			●
Karst (sinkhole)			●
Landslides	●	●—	—●
Liquefaction			●
Radon gas		●	
Regional flooding			●
Slope creep	●	●	
Subsidence	●	●—	—●
Tsunamis			●
Volcanic eruption			●

Natural processes are numerous. These include landslides, slope creep, soil expansion and contraction, subsidence (consolidation), erosion, regional flooding, earthquake ground shaking, fault rupture, liquefaction, chemical or mechanical weathering, corrosive soil, tsunamis, volcanic eruption, karst (sinkhole collapse) and radon gas. Those processes considered life-threatening because of their extremely rapid onset and rapid impact on the building are earthquake ground shaking, landslides, fault rupture, liquefaction, tsunamis, regional flooding, sinkhole collapse and volcanic eruption. Other processes that are non-life-threatening because of their slow onset, but with equally damaging forces on buildings are soil expansion and contraction, subsidence (consolidation), slope creep, erosion, and corrosive soil. Groundwater, in particular near surface (vadose) groundwater, either as soil water, intermediate water and capillary (Driscoll, 1986), is not typically a process. However, it is responsible for triggering many processes that require water for activating movement. Consequently, groundwater is a process contributor. Human-made features or human-induced actions, such as site drainage systems or irrigation practices, are also process contributors. For example, a shallow slump-type landslide can be caused by surface soil saturation triggered by a leaking irrigation pipe.

As for the RGE, evaluating the occurrence potential of a geologic process, or identifying a hazard on the property, is performed using empirical judgement by the practitioner and individually scored on a scaled bar-graph, Figure 5. Further, each potential process can be evaluated for pre-hazard risk. Accordingly, a score of 0 represents no potential for occurrence, 1 is low, 2 is moderately low, 3 is moderately high, and 4 is high potential. Any score above 4.0 is reserved for hazards. Processes can be added or removed from the bar-graph, for applicability to the region where the property is located. The processes shown generally apply to the geologic character of coastal southern California. An example for

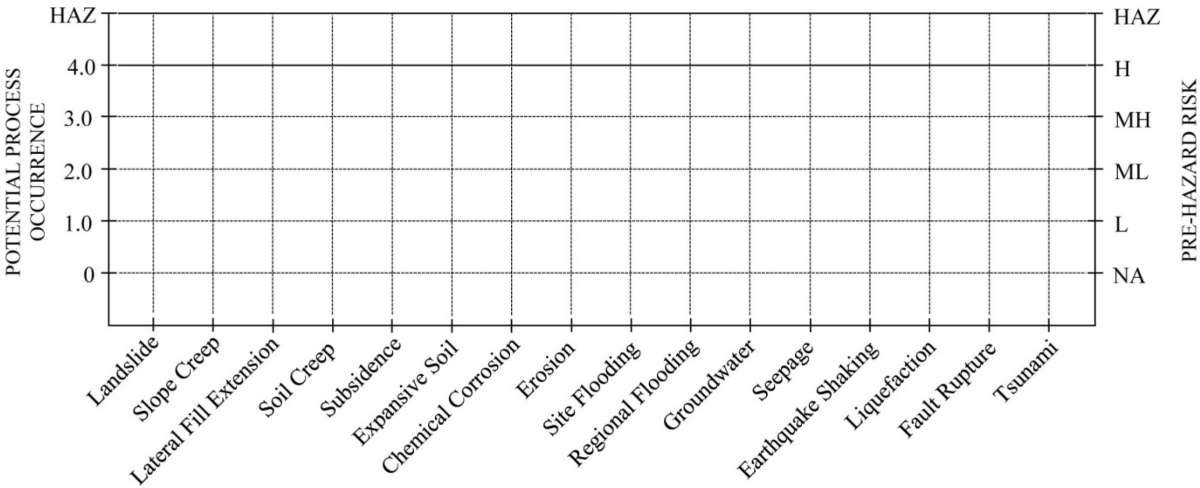


Figure 5. A scaled bar graph to score the potential occurrence and pre-hazard risk of various geologic processes and hazards. Scale ranges from 0 to 4, and HAZ. Abbreviations: NA=not applicable, L=low, ML=moderately low, MH=moderately high, H=high, HAZ=existing hazard.

scoring the potential occurrence and pre-hazard risk of each indicated processes is shown in Figure 15, in the section Example RGE within this chapter.

Part 2- Geologic Hazards

Geologic hazards account for the loss of hundreds of lives and billions of dollars in property damage in the United States every year. The 6.7M, Northridge, California, earthquake of 1994 took the lives of 57 people and caused an estimated $20 billion in building and infrastructure damages within 10 seconds of strong ground shaking (Darragh, et al., 1995). Hazards can be catastrophic, life-threatening and jeopardize the health, safety and welfare of people caught unaware or unprepared for the event. They can be localized to a single lot or widespread across vast regions. Scullin (1983) enumerates the damaging effects of hazards on many types of man-made structures. For these reasons understanding hazards is paramount for the determination of geologic risk.

A hazard is any process, natural or human-induced, that impacts property value, building stability, or safety for occupancy. Also, all hazards have associated risk. A hazard is a process, but a process is not necessarily a hazard. For the RGE, a hazard occurs within a property's legal boundaries. An exception would apply to a process on a neighboring property that becomes a hazard to the subject site.

Hazards are expressed by extent and severity. The extent depicts its coverage over the site and the severity indicates its magnitude of influence on buildings or site improvements. Also, they may have a local or widespread lateral extent. They can have variable severity, whereas a hazard may exist on the site and have little effect to the building or site improvements, and conversely, a hazard may have unallowable impacts to a building or site improvements. Further, they can be individually scored on a scaled bar-graph based on their severity and impact to the building and site improvements, Figure 6. An example for scoring the severity of each indicated hazard is shown in Figure 16, in the section Example RGE within this chapter.

The terms “natural process” and “geologic hazard” are often used synonymously and interchangeably throughout the literature. This has created confusion within the industry (Shlemon, 1999). It is important to the home buyer’s understanding of the RGE that natural or human-induced processes are distinguished separately from natural hazards.

Geologic hazards are a reflection of the geomorphic character of a region (Gath, 1992). Hazards are numerous and develop from earth materials and earth processes (Nuhfer et al., 1993). Also, local weather and climatic conditions may activate some earth processes that can become hazards.

The location of a building, whether on a hillside or on level ground, may suggest a susceptibility or propensity for hazard occurrence; however, the location alone does not necessarily indicate a lesser or greater propensity for property damage. It is a common misconception with home buyers that buildings located on “flat valley lots” are less subject to hazard-induced damage when compared to those located on “sloping hillside lots.”

There are three basic types of ground motions associated with most hazards. These are vertical, horizontal and shaking. Vertical motions are derived from subsidence,

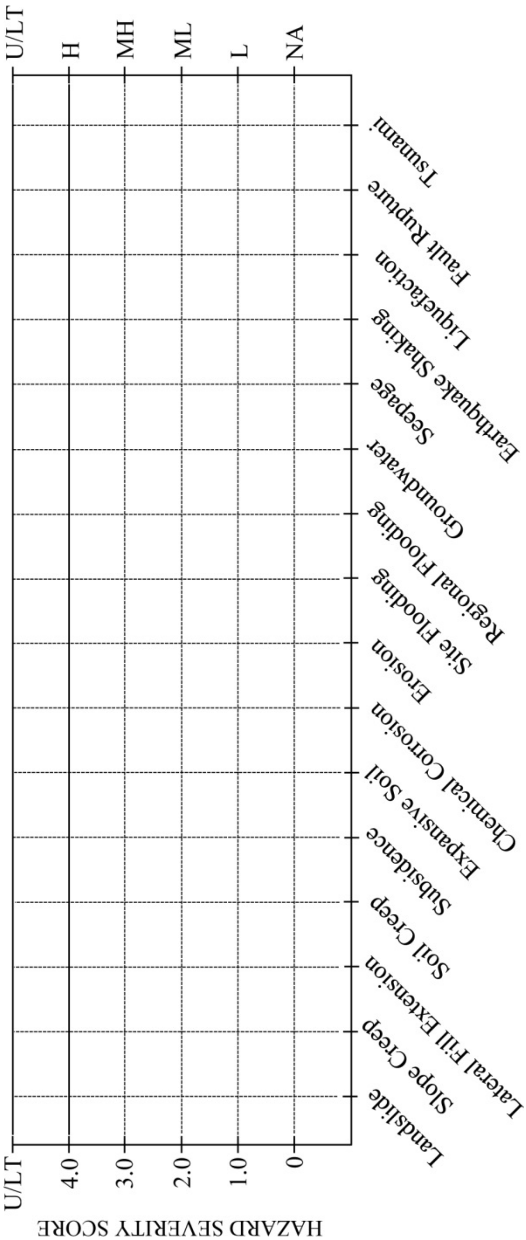


Figure 6. A scaled bar graph to score the severity of geologic hazards. Scale ranges from 0 to 4, and U/LT. Abbreviations: NA=not applicable, L=low, ML=moderately low, MH=moderately high, H=high, U=unallowable, LT=life threatening.

liquefaction, landslides, slope creep, and expansive soil shrinkage and heave. Horizontal motions can occur from liquefaction, landslides and slope creep. Earthquakes generate surface-waves that create vertical and horizontal ground motions. Each motion directly influences the performance of a building's foundation. The indicators produced reveal the geologic impact to the building.

The occupant of the property can unknowingly trigger hazards that affect the stability of a building. This is referred to as "homeowner-induced geologic impact" (Audell and Baghoomian, 1995). For example, over-irrigation and ineffective site drainage can cause expansive clay to heave a building foundation.

Part 3- Geologic Impact

A hazard's effect of ground movement on a building is "geologic impact." The term was first used by the author (Audell, 1993) to describe the severity of distortion (damage) caused by various hazards. Assessing impact is required for the evaluation of geologic risk.

The RGE assessment of impact uses a practical, performance-based, systematic model (or method) that employs nomographic integration of floor deflection, crack character, and distortion criterion comparable to recognized allowable category limits appropriate for residential buildings. Another approach by Boone (1996 and 2001) uses a quantitative mathematical, structural engineering method that includes strain superposition, ground deformation patterns and critical strain concepts. His concern is the over- or under-estimation of building damage by using elementary models based on single criteria, such as either crack dimension or floor deflection. While Boones' model is valid for estimating building damage, its complexity interferes with practicality. Given full consideration, the field evaluation of geologic impact must utilize readily available data from site observations and measurements, requires rapid determination (often in minutes) of the category of damage, and be based upon an integrated, comparative analysis system, where the results can be very accurate and real time.

Hazard induced foundation displacement is considered either uniform or non-uniform. Uniform displacement in residential buildings is rare and non-uniform displacement is typically the most common. For the RGE, displacement of the foundation, whether uniform or non-uniform, from its original (as-built) level position, is a geologic impact. The distortion indicators produced are evaluated to determine the category of impact to the building.

Buildings are expected to distort relative to the hazard(s) affecting the property. Distortion could be the result of aseismic or seismic (earthquake) related ground movements. Depending upon the hazard, impact to a building could worsen with time, and without intervention may become irreversible. Also, impact is time independent.

Diagnostic impact indicators are readily observable physical, strain-type features that result from building distortion. These indicators are divided into two categories: 1) primary, and 2) secondary. Primary indicators are cracks in walls, slabs, footings, and floor deflection. Secondary indicators are bowed walls, doors that swing, doors that jam in their frames, and 'V' gaps at door or window frames. Both are found in structural and architectural elements of the building. Primary indicators are the most informative; however, when not available for observation greater emphasis is placed on secondary indicators. The dimension of the indicators when compared to their allowable limits represents a category (level) of impact to the building.

The most obvious distortion indicator is cracks. Cracks in walls, slabs and footings have been classified by the Crack Classification System (Audell, 1998 and 2006). Several patterns are referred in discussions related to building distortion. Table 2 presents the crack nomenclature, abbreviations and types of foundation movement required to create the crack.

There are two basic types of non-uniform foundation displacement in buildings: 1) vertical deflection, and 2) horizontal extension or drift. Deflection, either differential flexural or planar-tilt types represent vertical upward (heave) or downward (settlement) displacement. Extension typically refers to pull-apart or lateral drift displacement. Severe subsidence or expansive clay heave can deflect and extend a foundation simultaneously. And, both can result from horizontal and vertical ground motions produced during an earthquake. Large permanent lateral deformation of the superstructure caused by foundation deflection or extension typically degrades vertical load carrying capacity.

Foundation displacement, measured by performing a floor level survey either by using a manometer or auto-leveling laser, will indicate four main components pertaining to vertical (settlement or heave) deflection. As for differential, flexural-type foundation settlement, three of these components were initially recognized and discussed by Skempton and

Table 2. Crack nomenclature and abbreviations[1].

CRACK NAME (Crack Classification System)	LOCATION	CRACK ABBREVIATION	FOUNDATION DISPLACEMENT S=Settlement H=Heave E=Extension
Normal Vertical Tension Crack-Type 1&2	Wall	NVTC-1&2	S
Reverse Vertical Tension Crack-Type 1&2	Wall	RVTC-1&2	H
Pull-apart Vertical Tension Crack	Wall	PVTC	E
Seismic Vertical Tension Crack	Wall	SVTC	S, H, E
Normal Diagonal Tension Crack	Wall	NDTC	S
Reverse Diagonal Tension Crack	Wall	RDTC	H
Seismic Diagonal Tension Crack	Wall	SDTC	S, H, E
Normal Horizontal Tension Crack	Wall	NHTC	S
Normal Vertical Shear Crack	Wall	NVSC	S
Reverse Vertical Shear Crack	Wall	RVSC	H
Normal Horizontal Shear Crack	Wall	NHSC	S
Reverse Horizontal Shear Crack	Wall	RHSC	H
Seismic Horizontal Shear Crack	Wall	SHSC	S, H, E
Normal Vertical Compression Crack	Wall	NVCC	S
Normal Diagonal Compression Crack	Wall	NDCC	S
Normal Horizontal Compression Crack	Wall	NHCC	S
Normal Oblique Tension Crack	Slab	NOTC	S
Pull-apart Oblique Tension Crack	Slab	POTC	E
Reverse Oblique Tension Crack	Slab	ROTC	H
Seismic Oblique Tension Crack	Slab	SOTC	S, H, E
Normal Parallel Tension Crack	Slab	NPTC	S
Reverse Parallel Tension Crack	Slab	RPTC	H
Pull-apart Parallel Tension Crack	Slab	PPTC	E
Seismic Parallel Tension Crack	Slab	SPTC	S, H, E
Normal Radial Tension Crack-Type 1&2	Slab	NRTC-1&2	S
Reverse Radial Tension Crack-Type 1&2	Slab	RRTC-1&2	H

1. See Audell (2006) for complete explanation.

MacDonald (1956), and in some cases are still used by the industry for the design and evaluation of building performance. These components with updated terminology, as well as another component used by Boone (1996), are presented below:

- δ/l, maximum angular distortion (Skempton and MacDonald, 1956),
- Δ, maximum differential displacement (Skempton and MacDonald, 1956),
- ΔS, maximum end-to-end differential displacement (Boone, 1996), and
- ρ, maximum displacement (Skempton and MacDonald, 1956).

These components generally reflect the flatness and levelness of a floor, but also depict the dimension and relationship of differential deflection (flexural and planar-tilt types) in foundations. δ/l represents the greatest pitch (slope or flatness) of the floor, Δ represents the greatest vertical difference in elevation (flatness) between two points located anywhere on the floor, ΔS represents the greatest vertical end-to-end difference in elevation (levelness) at opposite sides or corners of the building, and ρ represents the greatest vertical difference between a point located anywhere on the floor found above or below the original floor level (OFL). For δ/l, Δ and ρ, these components may be found at central areas, such as in raised-floors with spread footings, or side locations, such as in slab-floors with continuous footings, although ΔS is exclusive to the end-to-end perimeter locations of either type of foundation. However, if the OFL is unknown or if no point on the floor is deemed to represent the OFL, then defining ρ is not possible. The comparison of the Skempton and MacDonald settlement model and RGE displacement model is shown in Figure 7.

Three situations for the relationship of Δ or ΔS and ρ can occur depending on the known location of the OFL and the displaced foundation: (1) differential settlement or heave of the entire floor below or above the OFL, then $\rho > \Delta$, ΔS; (2) differential settlement or heave of the entire floor below or above the OFL, but where part of the floor is at the OFL, then $\rho = \Delta$, ΔS; and (3) combination differential settlement and heave of floor where a part of the floor is above the OFL and part is below the OFL, then $\rho < \Delta$, ΔS. Where $\rho < \Delta$, ΔS, then ρ is inconsequential and Δ or ΔS is considered maximum displacement. This also is the case if the OFL is unknown for any situation. Further, end-to-end ΔS displacement may not necessarily indicate overall foundation tilt. Only the maximum dimensions of δ/l, Δ, ΔS and ρ are analyzed for floor deflection.

As for evaluating Δ and ΔS, three basic floor configurations can depict flat verses level relationships if ρ is unknown. These configurations are: 1) a floor is level but not flat, then $\Delta > \Delta S$, 2) a floor is flat but not level, then $\Delta S > \Delta$ and 3) a combination of both (most common), a floor is neither flat nor level. In this case, two possibilities exist depending which is greater, flatness or levelness, and these are: 1) the floor is more flat than level, then $\Delta S > \Delta$ and 2) the floor is more level than flat, then $\Delta > \Delta S$.

Another, lesser component of foundation displacement is total settlement. For design purposes, it typically means the expected total settlement of a building for its designated peri-

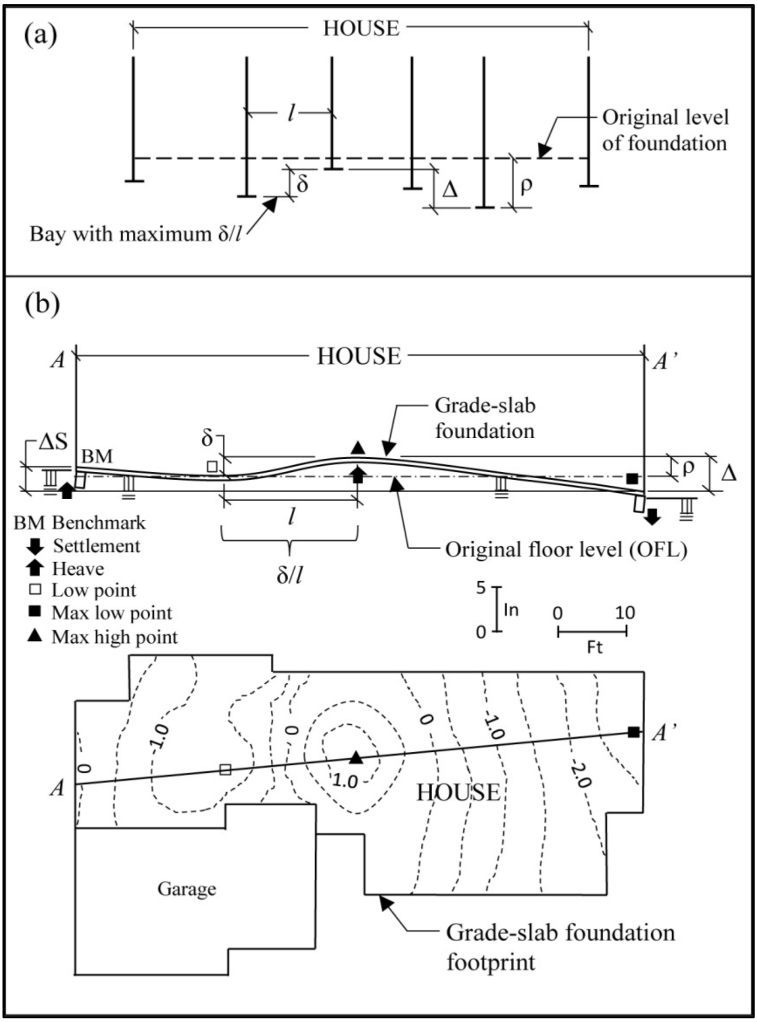


Figure 7. Comparison of Skempton and MacDonald (1956) model (a) with RGE model (b). Model (b) shows foundation deflection components relative to floor level survey. Abbreviations: δ/l=angular distortion; Δ= differential displacement; ΔS=differential end-to-end displacement; ρ=maximum displacement.

od of life. For the RGE, it is not considered in the evaluation for geologic impact.

Lateral ground movement causes extensional foundation displacement, or horizontal pull-apart, and is exhibited primarily by slab cracks and occasionally by wall cracks. It is determined as the summation of slab and footing crack separations. Boone (2000) asserted that horizontal displacement is critical to evaluating building performance. However, depicting the degree of extension relative to the total dimension of the foundation, especially when exact as-built distances to building perimeters are unknown, makes this effort difficult. This type of displacement typically creates PPTC-type slab cracks, as shown in Figure 8. Displacement is identified by the singular occurrence of a slab crack with the widest separation, or by multiple slab cracks with narrow separations. The total separation of all slab cracks exceeding one inch is considered severe foundation damage (Boscardin and Cording, 1989; and Day, 1998). Extension also creates vertical wall cracks (e.g., NVTC- and PVTC-types), depending upon the hazard inducing movement.

The entire house foundation can laterally drift. It can occur during liquefaction (lateral spread), landslide or slope creep of a hillside. On hillside properties composed of a clay fill-wedge, foundation drift may also result from lateral-fill extension. Typically, this condition becomes evident when a PPTG-type gap develops between the garage slab and driveway construction joint, or when a PVTC-type crack occurs in block landscape walls constructed parallel to the axis of fill soil extension. Lateral foundation drift can also occur because of severe subsidence and present

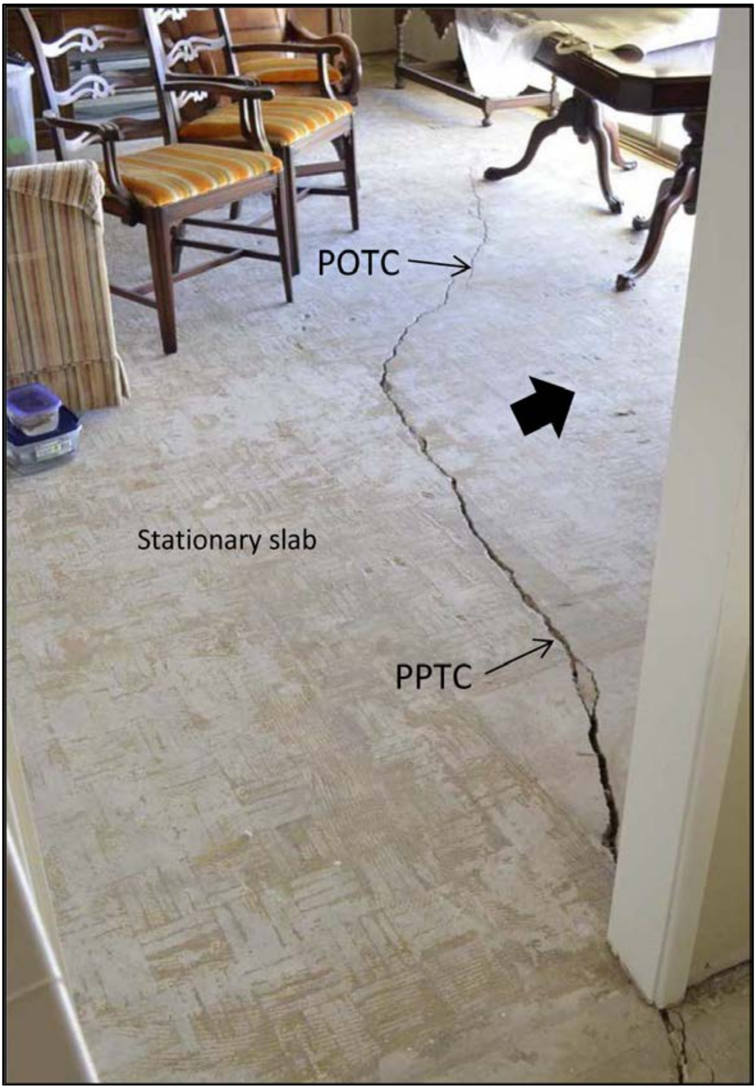


Figure 8. A PPTC- and POTC-type slab crack. Arrow indicates direction of horizontal extension of house foundation toward the rear yard top-of-slope.

similar PPTG's in slabs and PVTC's in walls. The stretching of underground utility pipes (water, sewer and gas) below the building, and especially where connected to street main-pipes also become a concern. The maximum dimension of lateral foundation drift, evident by the presence of a PPTG-type gap located between the garage slab and driveway construction joint, is one inch.

Earthquake ground shaking may induce foundation deflection, extension or lateral drift, and typically depends on the soil characteristics below the foundation. If a building overlies a saturated non-cohesive, granular sand-type soil with a propensity for subsidence or liquefaction, then foundation settlement, pull-apart and lateral drift may occur. However, if a building overlies a cohesive, stiff clay-type soil, then these types of foundation movements will probably not occur (Seed and Idriss, 1982).

Therefore, distinguishing the cause of distortion in a building that has previously settled and then subjected to violent seismic shaking may be difficult to ascertain with any degree of scientific certainty. Evidence for differentiating aseismic and seismic damages is often reflected in the type of wall crack patterns. A preponderance of SVSC-, SDSC- and SHSC-type wall cracks and the overprinting of a seismic signature on aseismic cracks may verify determinations.

Floors distort to three classic types of configurations: 1) dished (edge-lift), 2) domed (center-lift), and 3) pitched (Day, 1994). Downward vertical floor deflection is termed "settlement" and upward vertical floor deflection is termed "heave." In expansive clay soil settings, floors may become excessively distorted and display a combination of all three configurations (Holland et al., 1980). Crack patterns in walls, slabs and footings, when correlated with floor deflection can aid in identifying the geologic hazard likely responsible for movement (Audell, 1996 and 2006).

Rigid foundations, such as post-tensioned slabs, may undergo planar-tilt (or rigid-body) displacement. The dimension of impact indicators can be incongruent with the degree of displacement because of the lack of significant differential foundation bending. Although superstructure distortion is minimal, eccentricity is evident by doors that swing voluntarily and tilted walls. Wall and slab cracks may be present, but are typically very narrow in separation. Because δ/l and Δ are not typically related to planar-tilt, emphasis is placed on ΔS (maximum end-to-end differential displacement) and the slope (rise/run) of the floor. The allowable limit for ΔS would apply.

The International Building Code (IBC, 2010) and California Building Code (CBSC, 2010) requires geotechnical engineers to specify the "expected" settlement or heave of buildings proposed for construction based on the surface and subsurface soil-rock parameters of the property (CBSC, 2010, Chapter 18A, Section 1803A.7.6). From this information the geotechnical and structural engineer recommends the appropriate type of foundation system for building support. For a residential building, the typical maximum expected settlement (or heave) specifications for the foundation are: 1) for δ/l, 1/2"v:30'L, 2) for Δ, 1/2 inch settlement or heave, and 3) for ΔS, 3/4 inch settlement or heave. Often, residential buildings will experience settlement or heave early in their life that exceeds the "expected" design limit.

For nearly a half-century engineers recognized the need to establish or reference allowable limits for building settlement. These are discussed in ASCE (2003 and 2006), Boone (1996 and 2001), Boscardin and Cording (1989), Burland and others (1977), Burland and Wroth (1978), Day (1990, 1998), Duncan (1993), Feld (1965), Freeman and others (2002), Grant and others (1974), Hanson (1996), HOW (1986), Koenig (1992), Meehan and Karp (1994), Polshin and Tolkar (1957), Poulos and others (2002), Skempton and MacDonald (1956), and Wahls (1981). The landmark paper "The Allowable Settlements of Buildings" by Skempton and MacDonald (1956) first established preliminary design and distortion limits for building settlement. A compilation of allowable settlement limits as published by many of these previous workers is presented in Table 3.

According to the literature and Table 3, there is disagreement about the exact allowable limits for residential building distortion indicators. Different limits for cracks in walls, slabs and floor deflection (δ/l and Δ) have been reported. Altogether, the differences for residential buildings may be small, but a consensus has yet to be achieved. Controversy has developed in establishing fixed limits for all types of buildings, as well as flexible limits for specific types of buildings. Standard limits are appropriate for the RGE.

Another important criterion for evaluating impact is the as-built construction tolerance of floor slabs relative to their flatness and levelness. Floors are typically built within a tolerance of 3/16 inch vertical in 10 horizontal feet of flatness (δ/l) and 3/4 inch of level (ΔS), (ACI, 1994 and Means, 1998). A geotechnical study of new residential post-tension

Table 3. Various allowable limits for building distortion.

REFERENCE	ALLOWABLE LIMITS			
	WALL CRACK (in)	SLAB CRACK (in)	DIFFERENTIAL DISPLACEMENT (Δ, in)	ANGULAR DISTORTION (δ/l)
ASCE, 31-03 (2003)[2]	1/8[4]			
Bjerrum (1963)[1]				1/150
Burland, et. al. (1977)[1]		3/16[3]		
Day (1998)[1, 7]	3/16[3]		2 - 3	1/120-1/175
Grant, et. al. (1974)[1, 8]			1.2[10] 2.2[11]	1/300
HOW (1986)[1, 5]	1/8[3]	1/4		1/128
Meeham and Karp, (1994)[1, 7]				1/120-1/240
Poulos, et. al. (2002)[1, 6]				1/250-1/500
Skempton and MacDonald (1956)[1, 8]			1.25[10] 1.75[11]	1/150
USACE (1990)[1,9]			0.5	1/150
Wahls (1981)[1]				1/150

[1]Aseismic induced distortion; [2]Seismic induced distortion; [3]Crack separation in drywall or plaster; [4]Crack separation in reinforced and unreinforced masonry walls; [5]Home Owner Warranty; [6]Wood framed buildings; [7]Wood framed grade-slab houses; [8]Load bearing brick walls or brick panels in traditional-type frame buildings using isolated or raft foundations; [9]U.S. Army Corps of Engineers; [10]Sand; [11]Clay.

grade-slab foundations indicated that as-built flatness of 1 inch vertical in 30 horizontal feet (δ/l) and levelness of 1/2 inch (ΔS) could be expected (Noorany, et al., 2005). These tolerances are factored into the allowable limits to assess foundation displacement.

The rate at which building displacement occurs can influence the level of damage. A high rate of differential displacement can induce more building damage that slower rates of displacement, because of the inability of the building to adjust to rapidly changing ground movement conditions (Feld, 1968).

Evaluating impact should not overly emphasize one specific indicator, but must correlate all indicators for an unbiased and standardized determination. This requires establishing a fixed allowable limit for each indicator that corresponds with the literature (see Table 3). As for floor deflection, the limit must include construction tolerances. Presented in Table 4 are the fixed limits to be used for calculating impact.

Geologic impact, based upon the dimension of primary impact indicators, is determined by a four-sided matrix-area nomogram (Figure 9). The four elements of the nomogram are: 1) the dimension of cracks in walls, 2) the dimension of cracks in slabs, 3) the dimension of cracks in footings, and 4) the dimension of floor deflection. All four are plotted to create a node envelope within a boundary field of increasing impact. An example for determining the category of geologic impact based on primary indicators is shown in Figure 17, in the section Example RGE within this chapter.

Table 4: Allowable limits for primary geologic impact indicators in residential buildings.

PRIMARY IMPACT INDICATOR (vertical and horizontal displacements)	ALLOWABLE LIMIT in (mm)
Wall crack separation (plaster or drywall)	1/8 (3.2)
Slab crack separation	1/4 (6.4) or 1/8 (3.2)*
Footing crack separation	1/8 (3.2)
Angular distortion or slope, δ/l	1/150
Differential displacement, Δ	2 (50.8)
Maximum displacement, ρ	2 (50.8)
End-to-end differential displacement, ΔS	2 (50.8)
Lateral building extension/drift (separation)**	1 (25.4)

*post-tension slabs,
**not used for calculation of primary geologic impact

For the floor deflection side of the matrix nomogram, the levels indicated are the product of Δ, ΔS or ρ multiplied by δ/l. The greatest displacement of Δ, ΔS or ρ is used. The pertinent equation is shown below:

Eq. (1): $(\Delta, \Delta S, \rho)(\delta/l) \times 10^2 = \textit{floor deflection}$

This equation is used for differential flexural and planar-tilt type foundation displacement. Conversion of floor deflection values and the relationship to geologic impact is shown in Table 5.

Determination of δ/l requires measuring at least 15 feet of horizontal distance (Skempton and MacDonald, 1956) or preferably, the entire foundation. Shorter lengths may yield an inaccurate determination.

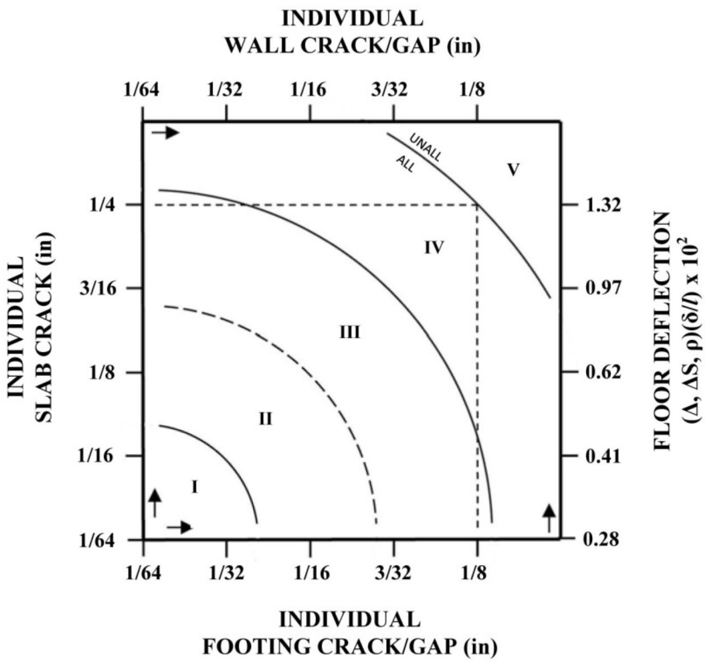


Figure 9. Quadruple curve matrix-area nomogram to determine geologic impact based upon primary indicators. For abbreviations refer to text. Modified from Audell (1999a).

Geologic impact, based upon the dimension of secondary indicators, is determined by using a four-sided matrix-area nomogram (Figure 10), which depicts the eccentricity of the building. The four elements of the nomogram are: 1) the percentage of doors that swing, 2) the percentage of doors that jam, 3) the percentage of bowed walls, and 4) the dimension of "V" gaps at door and window frames. All four are plotted to create a node envelope within a boundary field of increasing impact. The fixed limit for secondary impact indicators

Table 5. Conversion table for levels of floor deflection.

CONVERSION FOR LEVELS OF FLOOR DEFLECTION		
CATEGORY OF GEOLOGIC IMPACT	FACTORS (Δ, ΔS, ρ, δ/*l*)	CONVERSION* (Δ, ΔS, ρ)(δ/*l*) x 10^2
I	Δ=1 in ΔS=1 in ρ=1 in δ/l=1/360	0.28
II	Δ=1.25 in ΔS=1.25 in ρ=1.25 in δ/*l*=1/300	0.41
III	Δ=1.5 in ΔS=1.5 in ρ=1.5 in δ/*l*=1/240	0.62
IV	Δ=1.75 in ΔS=1.75 in ρ=1.75 in δ/*l*=1/180	0.97
V	Δ=2 in ΔS=2 in ρ=2 in δ/*l*=1/150	1.32

*Converted levels have no units. For conversion use either Δ, ΔS, or ρ, whichever is greater.

are provided in Table 6. The practitioner visually estimates and physically measures if necessary, the percentage and dimension of displacement of these indicators. An example for determining the category of geologic impact based on secondary indicators is shown in Figure 18, in the section Example RGE within this chapter.

The practice of interpolation may be necessary if there is a lack of sufficient data to complete the nomogram. Interpola-

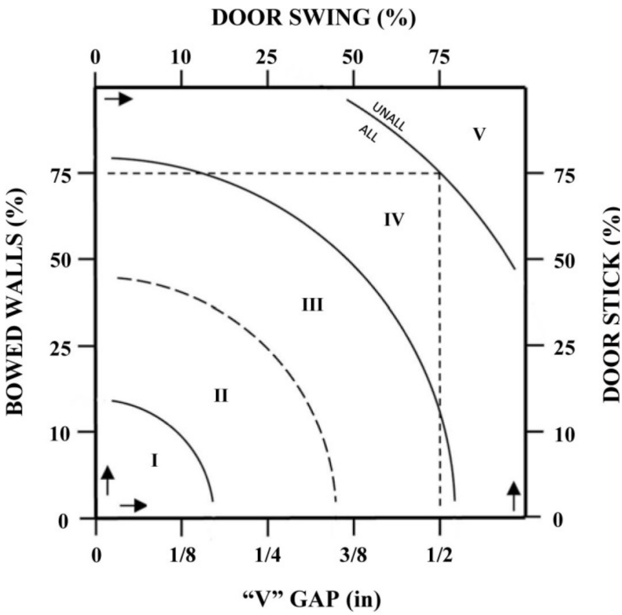


Figure 10. Matrix-area nomogram to determine geologic impact based upon secondary indicators. For abbreviations refer to text. Modified from Audell (1999a).

tion is acceptable providing that the inferred data correlate with the other supporting data. Impact indicators are often concealed within the building and inferring indicator data is required to create a node envelope.

Correlation of the primary and secondary nomograms determines the category of impact to the building. Impact is divided into five main categories that depict the severity of building damage. The elements that are damaged are typically referred to as cosmetic, architectural and structural. The categories are: I-low, II-moderately low, III-moderately high,

Table 6: Allowable limits for secondary geologic impact indicators in residential buildings.

SECONDARY IMPACT INDICATOR	ALLOWABLE LIMIT
V-gaps	1/2 inch separation
Bowed walls	75% of all walls
Door swing	75% of all doors
Door jam	75% of all doors

IV-high and V-unallowable. Categories I through IV represent allowable impact. Buildings of Category I and II display mostly cosmetic damage, whereas buildings of Category III and IV impact reveal cosmetic and architectural damage. Buildings of Category V impact will exhibit structural damage. Each category has defined zone boundaries.

A node envelope overlying a category boundary may require judgment to integrate the impact designation with the causative hazard. Categories may also be expressed as a range, such as III to IV, or with modifiers, such as plus (+) (e.g., Category II+) impact.

The category of impact also defines a building's safety for occupancy. The designation considers two factors: 1) the type of hazard impacting the building and whether it is life-threatening, and 2) the structural competency of the building to remain secure during geologic (or climatic) events that may generate strong vertical and horizontal applied loads, such as earthquake ground shaking. For example, a Category V building may sustain compounded damage from a life-threatening event that leads to structural failure.

Categories I through IV indicate that a non-life-threatening hazard affect the building. Because the building retains its structural competency they are safe for occupancy. Category V buildings present two different scenarios that determine safety for occupancy: 1) the hazard is non-life-threatening and the structural competency of the building is retained, and 2) the hazard is life-threatening and the structural competency of the building is compromised. A defining distinction between both scenarios is the ability for the building to withstand strong vertical and horizontal applied loads without failure. Overly stressed structural connections from prior movements present a predisposition for compounded damages to occur. This condition may or may not be obvious to the observer. In the first scenario it is expected that the building will sustain compounded damages; however, it will remain safe for occupancy during the load event. For the second scenario the building is not safe for occupancy. The determination of safety for occupancy for Category V buildings also requires the expertise of a professional structural engineer.

As for evaluating the safety for occupancy of earthquake damaged buildings, the American Society of Civil Engineers (ASCE), Federal Emergency Management Agency (FEMA), and Applied Technology Council (ATC) have descriptive categories (or levels) for structural and non-structural performance. The categories for structural performance (listed in decreasing safety performance) are: 1) immediate occupancy, 2) damage control, 3) life safety, 4) limited safety, and 5) collapse prevention. The categories for non-structural performance (listed in decreasing safety performance) are: 1) operational, 2) position retention, and 3) life safety. These current categories are defined in ASCE 31-03 (2003) and ASCE 41-06 (2006). However, Pekelnicky and Poland (2012) report that they will be revised in ASCE 41-13 (publication anticipated). The ASCE 41-06 structural performance and nonstructural performance levels of earthquake-induced building damage have not been correlated with the RGE categories of impact as described here, although, it is expected that they would be consistent.

The RGE performance-based categories presented here represent cumulative impact. A building using a slab-on-grade foundation serves as the example. The categories are:

<u>Category I</u>: This category represents an allowable, low level of impact to the building. The lower boundary limit dimensions of the primary and secondary indicators of this category are:

- Wall cracks: 1/64 inch separation
- Slab cracks: 1/64 inch separation
- Footing cracks: 1/64 inch separation
- Floor deflection: δ/l=1/350; Δ, ΔS, ρ=1.0 inch
- 'V' gaps: none
- Bowed walls: none
- Door swing: none
- Door jam: none

Impact may or may not be observed within the building by occupants. Occasional wall cracks in plaster may be present and would include CCS NVTC- and NDTC-types. These cracks would be closed to very narrow in separation, and would not have reopened through patch and paint younger than seven years. Cracks would not be found in drywall. Slab cracks such as NPTC- and NOTC-types, would be closed to very narrow in separation, and infrequent. Footing cracks are usually not present. Floor deflection is not perceived by occupants. Eccentricity is not present. Cosmetic building elements are not damaged. A few remedial repairs may be appropriate, but they would not be required. The structural competency of the building is not affected and the hazards are non-life-threatening, therefore, it is safe for occupancy. Strong earthquake ground shaking should not affect occupancy concerns.

Category II: This category represents an allowable, moderately low level of impact to the building. The lower boundary limit dimensions of the primary and secondary indicators of this category are:

- Wall cracks: 1/32 inch separation
- Slab cracks: 1/16 inch separation
- Footing cracks: 1/32 inch separation
- Floor deflection: δ/l=1/300; Δ, ΔS, ρ=1.25 inch
- ‘V’ gaps: 1/8 inch separation
- Bowed walls: 10 percent of all walls
- Door swing: 10 percent of all doors
- Door jam: 10 percent of all doors

Minor impact is observed throughout the building. A few wall cracks in plaster and drywall may be evident and include CCS NVTC- and NDTC-types. These cracks would be closed to very narrow in separation. Slab cracks, such as NPTC- and NOTC-types, would be closed to very narrow in separation and infrequent. Footing cracks may be observed. Floor deflection is not perceived by occupants. Eccentricity is hardly noticeable. Cosmetic building elements may show minor damage, such as hairline cracking in floor tile. Some remedial repairs may be required to minimize the hazard's impact to the building. The structural competency of the building is not affected and the hazards are non-life-threatening, therefore, it is safe for occupancy. Strong earthquake ground shaking should not affect occupancy concerns.

Category III: This category represents an allowable, moderately high level of impact to the building. The lower boundary limit dimensions of the primary and secondary indicators of this category are:

- Wall cracks: 1/16 inch separation
- Slab cracks: 1/8 inch separation
- Footing cracks: 1/16 inch separation
- Floor deflection: δ/l=1/240; Δ, ΔS, ρ=1.5 inch
- 'V' gaps: 1/4 inch separation
- Bowed walls: 25 percent of all walls
- Door swing: 25 percent of all doors
- Door jam: 25 percent of all doors

Moderate impact is observed throughout the building. Numerous cracks in plaster walls are present and most are very narrow to narrow in separation. Crack patterns such as CCS NVTC-, NDTC- and NHSC-types are frequent. Plaster walls display a greater frequency of cracking than interior drywall although patterns would be similar. Slab cracks, such as NPTC- and NOTC-types, are narrow in separation, and also frequent. Footing cracks such as NVTC- and NHSC-types, would be observed. Floor deflection is detectable by occupants. Eccentricity is obvious. Cosmetic and architectural building elements exhibit some damage, such as out-of-square door frames and jammed doors. Some remedial repairs may be required to minimize the hazard's impact to the building. The hazards are non-life-threatening and the structural competency of the building is not affected. The building is safe for occupancy. Strong earthquake ground shaking should not affect occupancy concerns.

Category IV: This category represents an allowable, high level of impact to the building. The lower boundary limit dimensions of the primary and secondary indicators of this category are:

- Wall cracks: 3/32 inch separation
- Slab cracks: 3/16 inch separation
- Footing cracks: 3/32 inch separation
- Floor deflection: δ/l=1/180; Δ, ΔS, ρ=1.75 inch
- 'V' gaps: 3/8 inch separation
- Bowed walls: 50 percent of all walls
- Door swing: 50 percent of all doors
- Door jam: 50 percent of all doors

Major impact is observed throughout the building. Wall cracks are common and would be observed at several door and window frame corners in plaster and drywall. Crack separation would vary from narrow to wide. These would include CCS NVTC-, NDTC- and NHSC-types. Slab cracks such as NPTC-types, are wide in separation, and also common. Footing cracks, such as NVTC-type, are present. Floor deflection is very detectable to occupants. Eccentricity is obvious throughout the house. Cosmetic elements are damaged such as the tearing of wall-paper, floor tiles lifting off slabs, or the separation of casing joints at door frame corners. Architectural elements are damaged, such as numerous doors that jam in the door frames or swing unassisted, bowed walls and "V" gaps at door and window frames. The upper category limit represents the allowable level for impact, indicating that the structural competency of the building is becoming affected. Extensive remedial repairs and foundation stabilization may be required to minimize the hazard's impact to the building, although the hazard(s) are not life-threatening. Therefore, it is safe for occupancy. Strong earthquake ground shaking should not affect occupancy concerns. The practitioner's professional judgment is required in these instances.

Category V: This category represents an unallowable level of impact and the onset of structural damage to the building. The lower boundary limit dimensions of the primary and secondary indicators of this category are:

- Wall cracks: 1/8 inch separation
- Slab cracks: 1/4 inch separation
- Footing cracks: 1/8 inch separation
- Floor deflection: δ/l=1/150; Δ, ΔS, ρ=2.0 inch

- ‘V’ gaps: 1/2 inch separation
- Bowed walls: 75 percent of all walls
- Door swing: 75 percent of all doors
- Door jam: 75 percent of all doors

Buildings with excessive floor pitch, very wide crack separations in walls, slabs and footings, and those with excessive eccentricity are classified in this category. Structural elements exhibiting damage would include the foundation, bearing posts, ceiling beams, and roof trusses. The structural competency of the building may or may not be compromised depending upon the hazard inducing damage. A non-life-threatening hazard could render a Category V building safe for occupancy. Conversely, a life-threatening hazard would render a Category V building unsafe for occupancy. Periods of strong earthquake ground shaking may cause localized or widespread structural damage depending on the severity of impact prior to the event.

Category V buildings may be hazardous to public safety, health and welfare. As recommended by many state agencies (e.g., California Emergency Management Agency, Safety Assessment Program), licensing boards and professional society standards and ethics, if the practitioner encounters a building deemed unsafe for occupancy, their findings should be reported to the building official of the municipality where the property is located. Furthermore, a professional structural engineer should be involved to verify a Category V building’s safety for occupancy.

Part 4-Ground Activity

The Earth's surface and the ground below a building are constantly active relative to some geologic processes or hazard. Therefore, a building can be used as a gauge to measure the apparent rate of ground activity. The rate of activity is defined as the relationship of building distortion relative to time. It is classified as “historic” and “current.” “Historic” ground activity (HGA) integrates the dimension of wall and slab cracks to the age of the house. “Current” ground activity (CGA) integrates the first occurrence of a wall crack, as well as the recurrence of cracks to the specific age of the surface material (i.e. stucco, paint or patch) through which the crack propagates. Together, HGA and CGA characterize the hazard’s relative, absolute and real-time dynamics.

Geologic hazards may not exert the same rate of activity uniformly across a property. Properties consisting of multiple hazards make distinguishing ground activity associated with one hazard with that of another difficult. Also, results from the HGA and CGA graphs need not be complementary. Dynamic hazards may be dominant or subordinate, or increase or decrease in activity over time. A minimum and maximum, or average rate of activity should be determined.

Two double-curve area-graphs determine HGA and one triple-curve area-graph determine CGA. The HGA graph based upon wall crack dimension is shown in Figure 11 and the HGA graph based upon slab crack dimension is shown in Figure 12. The graph for CGA is shown in Figure 13. Examples for determining the rate of historic and current ground activity is shown in Figures 19, 20 and 21, respectively,

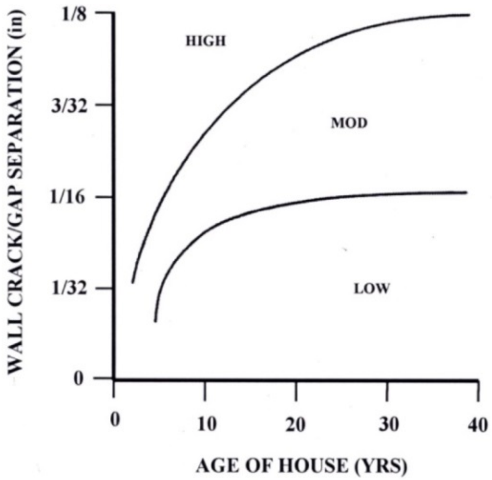


Figure 11. Double curve-area graph to determine historic ground activity based upon dimension of wall cracks/gaps versus the age of the house. Modified from Audell (1999b).

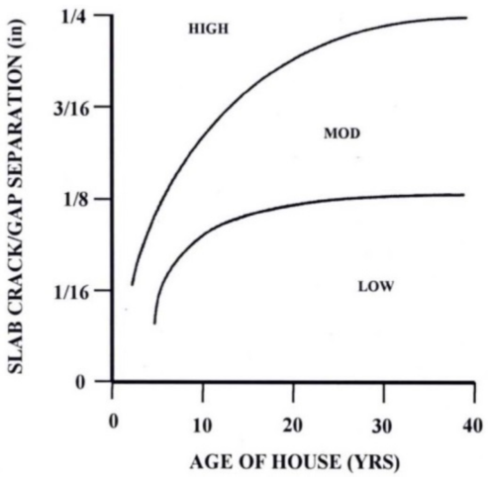


Figure 12. Double curve-area graph to determine historic ground activity based upon dimension of slab cracks/gaps versus the age of the house. Modified from Audell (1999b).

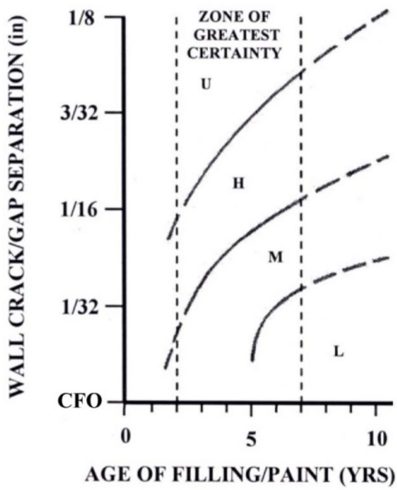


Figure 13. Triple curve-area graph to determine current ground activity based upon dimension of wall cracks/gaps versus the age of patch or paint. Modified from Audell (2006).

in the section Example RGE within this chapter.

The HGA graphs utilize two best-fit curves that partition the rate of ground activity in a 40-year track of time. The three areas are: Low, moderate and high. The lower curve is compound in shape and the upper curve is a simple radius shape. The lower curve's initial slope is steep from year 5 to year 10, and reflects incipient or low-rate of ground activity early in the life of the building. The upper curve's initial slope is also steep from year 3 to year 20, and reflects a high-rate of ground activity early in the life of the building. Between 20 and 40 years of age, both curves reflect the rate of activity during the middle and late age of the building. Usually, after 40 years, any additional activity, unless catastrophic, is considered inconsequential.

The CGA wall-crack graph utilizes three best-fit curves that partition the rate of ground activity in a 10-year track of time. The four bound areas are: Low, moderate, high and unallowable. A zone of greatest certainty constrains time between 2 and 7 years for any given material and identifies a real-time rate of ground activity. Further, "crack first occurrence" (CFO) in material younger than 2 years, or in material older than 7 years, has decreased certainty in the determination.

Determination of ground activity allows the practitioner to forecast additional impact to a building. Some hazards with high rates of ground activity are likely to create high levels of impact to a building in about 2 years. Defined rates of ground activity categorized by wall crack character are shown in Table 7.

Part 5-Geologic Risk

All buildings are at some level of real-time post-hazard geologic risk. Real-time risk is defined as the relationship of the category of impact relative to the current rate of ground activity. It represents the expectancy of the building to becoming additionally damaged from an imposing hazard. Risk expectancy is analyzed by the use of a quadruple curve-area graph as shown in Figure 14.

The Risk Expectancy Scale (RES) indicates the real-time risk of the building. It designates a numerical score that ranges from 0 to 5. The scale is divided into five boundary levels: 0 to 1 is low; 1 to 2 is moderately low; 2 to 3 is moderately

Table 7. Defined rates of ground activity determined by wall crack character.

RATE	DESCRIPTION
Low	Complexity: Simple Occurrence: Occasional Separation: Closed to very narrow Recurrence: In 10 year old patch or paint Growth: Live cracks become static within 2 years
Moderate	Complexity: Simple or compound Occurrence: Few Separation: Narrow Recurrence: In 5 year old patch or paint Growth: Live cracks become static within 5 years
High	Complexity: Compound to complex Occurrence: Many Separation: Wide Recurrence: In 2 year old patch or paint Growth: Live cracks remain live

high; 3 to 4 is high, and is allowable risk; and 4 to 5 is unallowable risk. It is subdivided into quarter increments. A description for each level of RES risk is provided in Table 8. An example for the determination of the RES score is shown in Figure 22, in the section Example RGE within this chapter.

The RES provides a standardized score that is meaningful to practitioners and other professionals working in the real estate industry. The score allows for comparative relationships to be developed, such as property to property, or a property within a geographic area. With caution, it may also be found useful in appraising property value. At any point in time, the real-time designation for risk is constant because

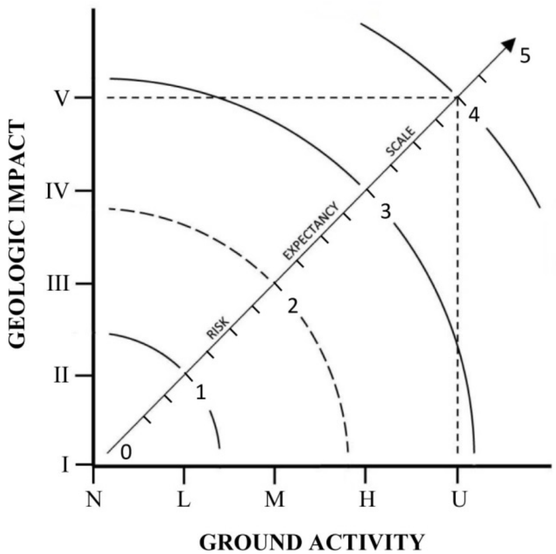


Figure 14. Quadruple curve-area graph to determine the Risk Expectancy Score (RES) based upon geologic impact versus ground activity. Modified from Audell (1999c).

impact and ground activity are assigned data points. Although in a relative sense, risk is variable because the rate of ground activity and level of impact can change over time. Therefore, impact may remain consistent or progressively increase depending on the rate of ground activity. This allows the RES score to vary with the rate of ground activity.

Real-time post-hazard geologic risk has a direct application to forensic engineering geology and geotechnical engineering (Dybel and Audell, 2016). From a forensic stand point, a practitioner may forecast increases in building damage based on risk, and specify the urgency for implementation

Table 8. Levels of geologic risk.

RES		DESCRIPTION
Allowable	0	Low geologic risk. Minor remedial improvements repairs could be implemented to maintain low risk score, but are not necessary. House is safe for immediate occupancy.
	1.0	Moderately low geologic risk. Small scale remedial improvements are required to manage risk score. Geotechnical monitoring is considered. House is safe for immediate occupancy.
	2.0	Moderately high geologic risk. Many remedial improvements are required to lower risk score. Geotechnical monitoring is recommended. House is safe for immediate occupancy.
	3.0	High geologic risk. Hazards are not life threatening. Major remedial and structural repairs are required to stabilize lot and building. Geotechnical monitoring is required. House is safe for immediate occupancy.
Unallowable	4.0 5.0	Unallowable geologic risk. For hazards not life threatening, house is marginally safe for occupancy. For hazards that are life threatening, house is not safe for occupancy. House is susceptible to collapse by strong earthquake ground shaking. Significant ground stabilization and structural repairs are required. Structural engineer opinion required.

of hazard mitigation recommendations. This information may be useful for averting catastrophes that may impact the health, safety and welfare of the public.

Consider a 10-year old building of Category III impact on a lot with a high rate of ground activity. The RES score is 2.5.

Property improvements were implemented and now ten years later, that same building is measured with Category III impact and the lot with a low rate of ground activity. The RES score is 1.5. Comparatively, the risk has reduced even though the level of impact has remained consistent. Management of the hazards has reduced the rate of ground activity which has improved the RES score.

For any property a RES 3, or lower, is the most desirable. A property with this score may be purchased and occupied immediately. Remedial improvements may be necessary to minimize the effects of the hazards influencing building performance. A property with an RES of 3 to 4 indicates the building is safe for occupancy; however, major repairs to the lot are necessary in order to avoid continued building movement. A property with an RES of 4 or higher indicates concerns with the building's safety for occupancy and the desirability for purchase. For these properties significant ground stabilization measures and building repairs are necessary to restore them to an RES 3 or better. Typically, these properties are listed for sale as distressed.

Certainty and confidence influences the determination of geologic risk. Where there is abundant data the RES score may be very accurate, whereas, where data is insufficient or where many data points are inferred, the RES score may be less than accurate. In these instances the practitioner may provide a range in RES score, using the lower score as the base and increase the RES score some percentage above the base level. A half-point increase is reasonable, but more would require justification, and should be based on the severity of the hazards affecting the house. Unjustifiable increases bring uncertainty regarding the quality of the data used for the analysis and objectivity of the study. Any adjustment made to the RES score is entirely at the prerogative of the practitioner, and should be based on sound empirical relationships discussed in this guideline.

The real-time RES score of a particular property conveys three points of information to the home buyer. These are:

- The safety of the building for occupancy,
- The expectancy of the building to incur additional impact from *future* (potential) and *current* (real-time) geologic hazards, and
- The urgency for the implementation of repairs to the building and lot.

The importance of determining geologic risk is critical to decision-making by home buyers interested in property purchase, home owners interested in hazard mitigation, and home sellers for the purpose of disclosure. Geologic risk may be equated with financial risk and the expense necessary to implement certain geotechnical recommendations. The risk assessment may decide the outcome of a real estate transaction or provide sufficient merit for seller nondisclosure litigation.

Example RGE

A hypothetical RGE is presented to show the method and analysis required to formulate a complete conclusion statement. The definition of terms is located in the glossary section and reference to crack pattern classification and nomenclature is drawn from the CCS.

A home buyer has entered into escrow to purchase a residential property and desires to perform an RGE. A professional engineering geologist (practitioner) has been hired and the home buyer has elected the Tier I level of study. The practitioner performs the study according to the guideline method indicated here. Also, the practitioner is knowledgeable about the geologic character of the development and construction aspects of the building. The home buyer understands that a conclusion statement will be presented at the end of the study.

This property is located in a coastal southern California terraced hillside development built 30 years ago. The development has a history of ground movement-related building damage. A single family residence located on a level lot with a rear yard descending slope. It is single level, wood-framed, and utilizes a conventional reinforced concrete grade-slab and continuous footing foundation system for support. Also, the exterior walls are plaster and stucco, and the interior walls are drywall. Neighboring properties have similar constructed houses and lot configurations. The entire lot consists of compacted fill soil which is composed of clay. In profile, the fill is wedge-shaped and deepens toward the rear yard slope. Marine claystone bedrock underlies the fill soil. Subsurface ground water is not present, but the surface soil is wet. Site drainage is sheet-flow and flowline-type which trends forward to the street, but numerous landscaped areas surrounding the building are depressed, which allows for local flooding. Turf and planter areas lack area drains, and the building lacks roof gutters. Planters are located adjacent to the house foundation and large areas of turf are located at the rear yard near the top of slope. A raised planter is located at the top of slope. Vegetation is lush and over-irrigated. Hardscape consists of concrete walks, patios and privacy walls at the side yard property lines. Portions of the interior and exterior walls of the house were repainted. At the rear of the house, interior and exterior walls were patched and painted five years ago, and at the front of the house, interior and exterior walls expose original paint.

Upon inspection of the site, the practitioner ascertains the geologic processes that could affect the lot. The processes identified are landslides, expansive clay, subsidence, slope creep, lateral fill extension, erosion, sulfate corrosion, local site flooding, a surficial ground water condition, and earthquake ground shaking. All of these processes and process contributors are also common to the entire development.

With further inspection, the hazards which affect the building and site improvements become known. These are expansive clay, subsidence, slope creep, local site flooding and a surficial soil saturation condition. All of these hazards are dynamic except for local site flooding, which is transient.

At the top of slope, where the landscape walls connect to the pilasters, CCS PVTG- and NVTG-type gaps are observed at the construction joints. Both types of gaps are caused by slope creep. The hardscape walks and patios are heaved evident by the many RRTC-type cracks located at the central area of the slabs. These cracks are typical of a swelling expansive clay.

Primary impact indicators are observed throughout the house. Many NDTC- and NVTC-type cracks are found in exterior plaster walls and interior drywalled locations, but are prevalent at door and window frame corners. These cracks are apparent in the original wall paint at rooms near the front of the house. A few NDTC-type cracks in drywall have reopened through 5-year old patch and paint at locations near the rear of the house. Carpets lifted in the family room have exposed a long NPTC-type slab crack trending parallel to the rear house wall. Where it encounters the house foundation a NVTC-type crack is found in the footing. A NOTC-type slab crack was found in the corner of the garage. Also, a floor level survey indicates that the rear half of the foundation has pitched down toward the rear of the house. The dimension of these primary indicators, along with their allowable limits, is presented in Table 9.

Table 9. Primary indicator data for Example RGE.

PRIMARY INDICATOR DATA			
INDICATOR	CRACK TYPE (CCS)	DIMENSION (in)	ALLOWABLE LIMITS (in)
Wall cracks in 30 year old paint	NVTC-1 NDTC	1/64 - 1/32 1/16	1/8
Wall cracks in 5 year old paint	NDTC	1/64	
Slab cracks	NPTC NOTC	1/16 - 1/8 1/8	1/4
Footing cracks	NVTC-1	1/64 - 1/32	1/8
Floor deflection:			
Differential displacement (Δ)		1.0	2.0
Angular distortion (δ/l)		1/240	1/150
End-to-end displacement (ΔS)		1-1/4	2.0
Maximum displacement (ρ)		unknown	2.0

Eccentricity is evident at the interior of the building. A few doors swing unassisted toward the rear of the house, and a few door frames are slightly out-of-square. In addition, a few doors jam within the frame when closed and a couple of doors have been shaved to fit. A few walls are bowed and found out-of-plumb. These secondary indicators, along with their allowable limits, are presented in Table 10.

Table 10. Secondary indicator data for Example RGE.

SECONDARY INDICATOR DATA		
INDICATOR	QUANTITY/ DIMENSION	ALLOWABLE LIMITS
Door swing	15%	75%
Door jam	20%	75%
Bowed walls	15%	75%
“V” gap at door/window frame	1/4 in	1/2 in

Following the inspection and tabulation of the data, the practitioner can evaluate the potential geologic processes for occurrence and their pre-hazard risk, the geologic hazards, category of impact to the building, the historic and current rate of ground activity, and finally, the RES score of post-hazard geologic risk. The results indicate numerous potential processes for occurrence and their respective score and identify the on-site hazards, Figure 15. The hazards are individually scored for their severity to the house and site improvements, Figure 16. Geologic impact is Category II as determined by use of Figures 17 and 18. The historic rate of ground activity is moderate (Figures 19 and 20), and the current rate of ground activity is moderate, Figure 21. Finally, the building has a 1.8 RES score, Figure 22.

The practitioner determined that building movement was likely caused by subsidence and was triggered and/or exacerbated by long-term excessive irrigation, extranormal rainfall

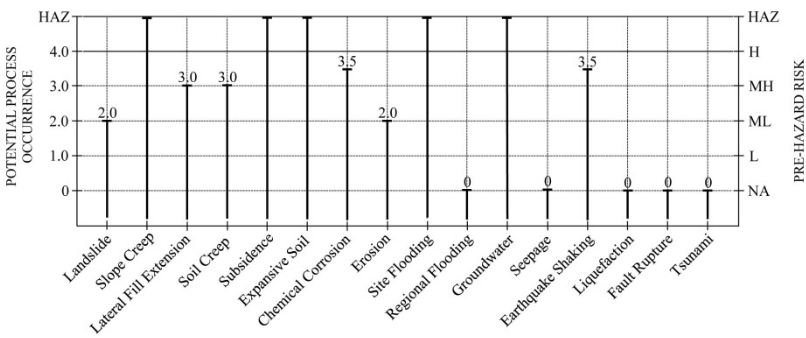


Figure 15. Potential occurrence and pre-hazard risk scores for Example RGE.

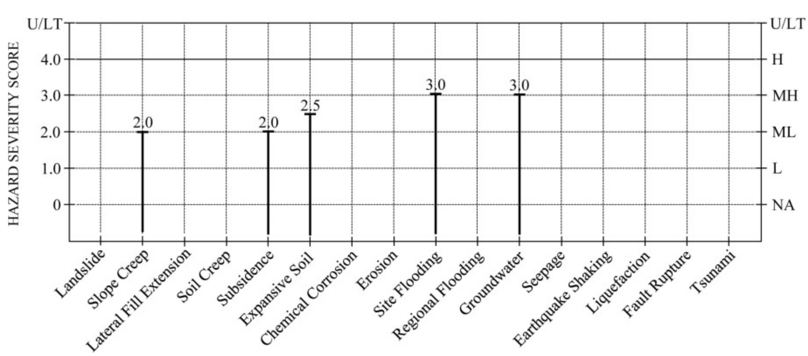


Figure 16. Severity scores of existing geologic hazards for Example RGE.

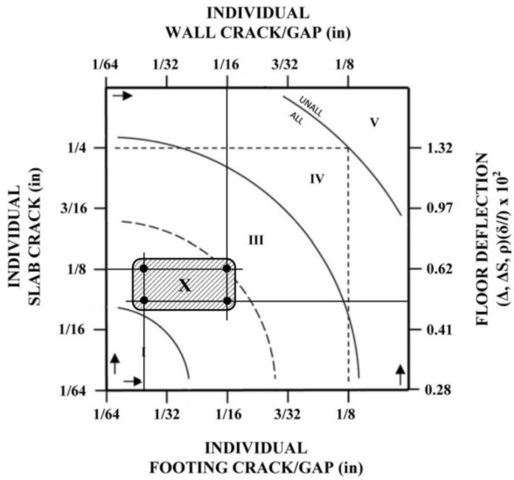


Figure 17. Determination of geologic impact based upon primary indicators for Example RGE. The level of geologic impact is Category II.

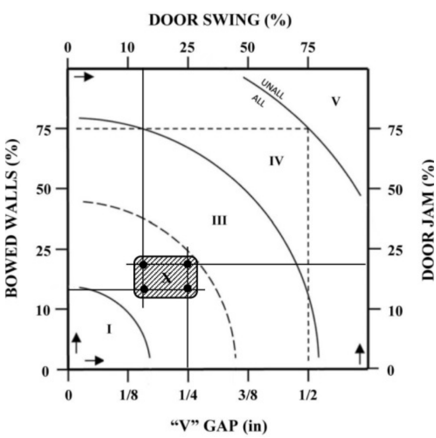


Figure 18. Determination of geologic impact based upon secondary indicators for Example RGE. The level of geologic impact is Category II.

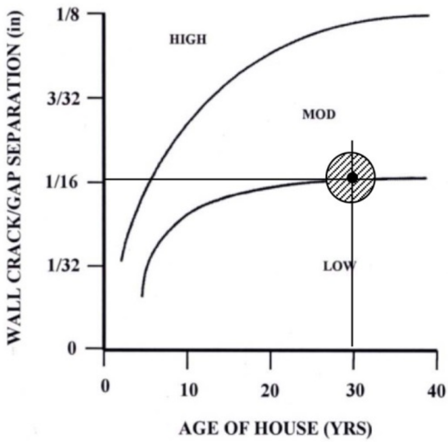


Figure 19. Determination of historic ground activity based upon dimension of wall cracks verses the age of the house for Example RGE. The level of historic ground activity is moderate.

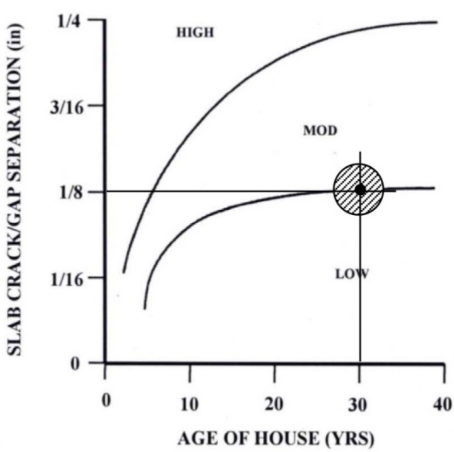


Figure 20. Determination of historic ground activity based upon dimension of slab cracks verses the age of the house for Example RGE. The level of historic ground activity is moderate.

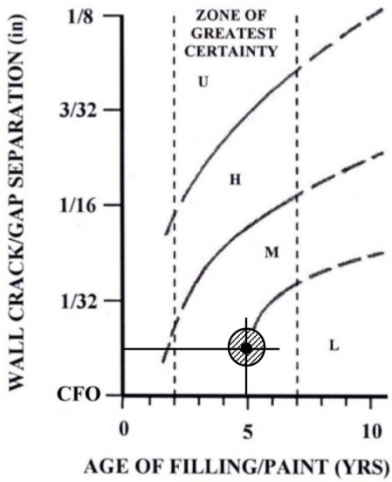


Figure 21. Determination of current ground activity based upon dimension of wall cracks verses the age of patch or paint for Example RGE. The level of current ground activity is moderate.

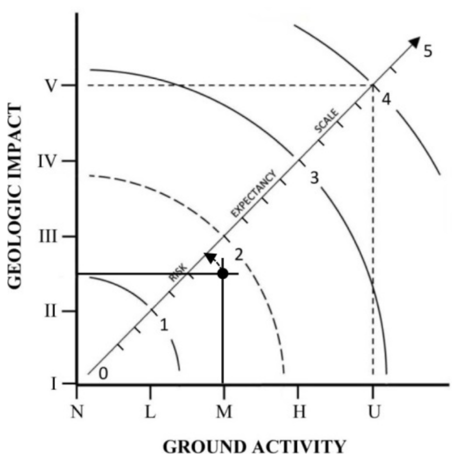


Figure 22. Determination of risk expectancy based upon the category of geologic impact verses the level of ground activity for Example RGE. The Risk Expectancy Score is 1.8.

and ineffective site drainage. At the slope, creep developed because of the softened clay. Also, wetting below the walks and patio caused the expansive clay to heave and crack the concrete. The impact to the house and improvements were primarily homeowner-induced. None of the hazards were considered life-threatening.

It was also determined that ground activity was constant throughout the life of the property. Moderate historic and current rates of ground activity affected building performance.

The practitioner concludes that this house has allowable geologic risk. None of the impact indicators had exceeded their allowable limits. Further, the level of certainty and confidence was high because of the availability and quality of the data obtained. The RES score is an accurate determination that did not require adjustment.

Although the house had sustained noticeable distortion, the appropriate remedial recommendations to manage and reduce additional impact would include drainage improvements and the reduction of irrigation. Other recommendations include patching of all cracks and gaps in the walls and slabs. After the recommendations have been implemented, site monitoring is performed to detect additional movement of the house. The practitioner informs the buyer that the house is safe for occupancy; however, if the recommendations are not implemented, additional impact to the building will result from continued ground movement. Also, after repairs, minor residual building movement may be expected as it achieves stability.

4

RISK MANAGEMENT

Risk management is herein defined as the actions performed by a homeowner to improve site preparedness. A properly prepared and maintained site may avert the potential occurrence of a hazard or minimize the consequences of an existing hazard. Associated pre-hazard and post-hazard risks can often be managed or minimized to protect the property. For residential properties there are four primary elements of preparedness:

- Site drainage systems,
- Irrigation systems,
- Landscape types and location, and
- Seismic reinforcement.

For the first three elements, water is a common constituent which can be effectively controlled and managed. It influences a hazard's level of ground activity and resulting impact to a building.

Homeowner maintenance varies considerably; however, those properties with proper drainage, irrigation practices and landscaping usually exhibit better building performance and the fewest hazards. These aspects have been discussed by McGill (1954), Holland (1980), Mathewson (1981), Mathewson and others (1975 and 1980), and Freeman and others (2002). The effectiveness of risk management is qualitatively assessed by using the following terms: Poor, fair, good and very good.

Buildings and their surrounding graded areas require drainage systems to maintain site stability. Essential building components include roof and deck gutters with accompanying down spouts tied into a surface drainage collection and conveyance system. Effective lot drainage, as related to surface-water flow management include established flowline gradients, the use of concrete walks or slabs to facilitate runoff, berms at the top of slope, surface drain systems on the building pad and slope face, the clearance of grade to the house wall weep screed, and a suitable location for runoff discharge and dispersal.

Landscape irrigation management is critical to controlling ground activity. Over-irrigation or under-irrigation will activate a number of processes that become hazardous to a building. For hillside fill soil lots composed of clay, over-irrigation induces soil subsidence, soil expansion, slope creep, and lateral fill extension. Under-irrigation induces soil shrinkage. Excessive irrigation also leads to formation of a surficial groundwater zone in all types of soil. The depth of soil saturation is dependent upon several factors such as soil consistency, the presence of shallow clay layers confining ground water movement, the permeability and porosity of the soil, and the amount of water percolating into the soil. In addition, the lateral movement of water may extend under foundations. Irrigation controllers set to maintain optimum and uniform moisture content can increase soil stability, especially with expansive clay-type soils. Efficient irrigation management considers the type of soil to be irrigated and the type of landscaping used in areas adjacent to the building foundation.

Trees located in proximity to house foundations can also induce building movement, either by root undergrowth or soil moisture egress. Root systems extract moisture from swelled and saturated expansive clay, inducing soil shrinkage, which then results in building settlement. Large trees may send roots a considerable distance to saturated soil below a neighboring house and induce foundation uplift. Engineered landscaping considers soil types and site drainage in addition to suitability of specific plants at particular locations.

Proper seismic reinforcement to the building and foundation system is critical to maintain structural integrity during and after an earthquake. The performance of the building determines the suitability for occupancy. Examples of seismic reinforcement are shear panels on exterior and interior wall frames and roof diaphragms, steel moment-frames for oversized doors and windows, steel ties or tie-downs at structural connections, bracing at the top and bottom of floor support posts on isolated footings, and bolting of the wall sill plate to the foundation. Light wood-framed residential buildings constructed after 1991 are generally stiffer and can withstand strong ground shaking better than earlier constructed buildings of similar type.

Risk management, as related to implementation of site or building improvements, is considered remedial or structural. Remedial improvements include drainage upgrades to buildings or to graded areas on the lot to facilitate the efficient management of surface water. These improvements are generally inexpensive. They include equipping a building with roof gutters, installing a surface drain system, or construction of appropriately sloped concrete patios and walks to assist in water runoff. Professional landscape architects design these types of site improvements. However, structural improvements to a building for earthquake retrofit, stabilization or releveling are often very expensive. Structural repairs are usually performed on buildings that have exceeded the allowable limits for displacement. This includes bracing an unreinforced masonry brick stem wall footing, releveling and underpinning a foundation with drilled piers, or compaction grouting adjacent to a house foundation. Often, geotechnical and structural engineers are involved in designing these types of foundation repairs.

The practitioner provides either verbal or written recommendations to the home buyer that address risk management. These recommendations are commensurate with the level of impact, ground activity or risk to the building. In some instances, a buyer's decision may rest with the expense involved in constructing the site improvements rather than the actual risk aspects associated with the property.

5

CERTAINTY AND CONFIDENCE

Several workers have emphasized the importance of both the identification of the conceptual uncertainty of data-derived conclusions, as well as the reasoning skills of practitioners. Both of these should be accounted for in risk analysis studies (Bond et al., 2007; Frodeman, 1995; and Pollack, 2007).

The practitioner informs the home buyer of the certainty and confidence in performing the RGE and the conditions that detract from the accuracy and completeness of the study. Certainty and confidence of the information provided is based upon a best-case situation where subsurface geologic characteristics (i.e., soil and bedrock character, groundwater regimes, fill soil depth and quality) and building elements (i.e., footings, slabs and walls) are known, readily identified or exposed for observation. A best-case situation can become compromised by the unavailability of these elements for observation often by unintentional or intentional (fraudulent) concealment. This applies to unknown specific subsurface conditions, wall paint less than 2 years or greater than 7 years in age, elastomeric exterior wall paint, covered slabs, wallpapered walls, straightened doors and/or anything that alters or obscures an original building element from observation. The risk determination should be of the highest level of certainty and confidence for the RGE to be of value to the buyer.

Scientific judgment is utilized in every evaluation, and it is dependent upon the practitioner's certainty and confidence. More judgment is required when there is a low level of certainty and confidence, and less when there is a high level of certainty and confidence. Further, judgment must not be influenced by external factors such as economic, social, or political interests, and should be based on geotechnical principles when considering the health, welfare and safety of the home buyer (or general public). The practitioner is allowed to use judgment to adjust a risk determination if certain factors warrant it. For example, the geologic risk to a house may be moderate because of a ground subsidence condition, but geotechnical judgment may change that determination to high because of a landslide adjacent to the house foundation.

6

LIABILITY MANAGEMENT

Of the various types of geotechnical studies, none pose greater risk of liability for the practitioner than the performance of the RGE. This liability can occur because of negligence, errors, omissions, misrepresentation, lack of due diligence, and fraud. The practitioner can be sued and held liable for damages incurred by the home buyer because of the professional opinions he renders to his client. However, this liability may also be shared by the seller, buyer's agent and broker, seller's agent and broker, and other home inspectors.

Practitioners, as professional engineering geologists or geotechnical engineers, are held to a level of technical competence when performing their duties (Hatheway and Kent, 1985). "A professional owes a duty to exercise the ordinary skill and competence of members of his profession during the course of his activities for the purpose of any person who foreseeably and with reasonable care and certainty may be injured by his failure to do so" (Patton, 1992). According to Olshansky and Rogers (1992), reasonable care is defined as "the exercise of care appropriate to a situation, or that degree of care which a person of ordinary prudence would exercise in the same or similar circumstances." In addition, Patton defines negligence as generally "the omission to do something which an ordinarily prudent person would have done under similar circumstances or the doing of something which an ordinarily prudent person would not have done under like circumstances." As for "standard-of-care," Patton expands the definition of negligence "as expressed in terms of compliance or noncompliance with a standard-of-care among like professionals of good reputation practicing in the same or similar community at the same time." The standard-of-care is typically determined from the testimony of experts in that field. Patton further expresses that the practitioner must maintain the standard-of-care by being aware of what others in the profession are doing, staying abreast of the advancing technologies and methods, and participation in formal and informal continuing education.

Fraud, as defined by Patton, is: "(1) the suggestion, as a fact, of that which is not true, by one who does not believe it to be true; (2) the assertion, as a fact, of that which is not true, by one who has no reasonable ground for believing it to be true (negligent misrepresentation); (3) the suppression of a fact, by one who is bound to disclose it, or who gives information of other facts which are likely to mislead for want of communication of that fact; or (4) a promise made without any intention of performing it. Anyone who willfully deceives another with intent to induce him to alter his position, to his injury or risk, is liable for any damage which is thereby suffered."

As applied to the RGE, Olshansky and Rogers (1992) identified vagueness in the law that creates a difficult situation for professional engineering geologists and geotechnical engineers. This is because there is little literature on the subject of practicing the RGE and what actually constitutes reasonable care, standard-of-care, or the applicable standard-of-practice. As a result, the practitioner may be at a loss about the prevailing standard-of-practice unless he or she is thoroughly familiar with the current practice by peers in a given area. The standards used by one practitioner may be different from another. However, should many practitioners include a task essential to the scope of work then it is construed as a standard-of-care. For example, today in the southern California area a few practitioners do not perform a floor level survey of the house they are evaluating, but most do, and that constitutes a standard-of-care. It also pertains to what the practitioner is obligated to inform the buyer. Probably, the greatest obligation is to inform the buyer of the geologic risk, perhaps as defined here.

A typical lawsuit begins when a new home owner discovers an undisclosed condition with the building, for example, structural settlement. After reviewing all the literature related to the purchase, especially the seller's transfer disclosure statement, and perhaps the geotechnical report prepared by the practitioner, the new buyer may feel that he was misled. To gain more information, the new home owner often contacts another practitioner for a second opinion. Upon learning that the condition is a major issue, the home owner will then retain an attorney. The attorney will then retain their own expert to prepare a certificate of merit, and file a complaint in the local court within the appropriate jurisdiction. A newly engaged expert will usually study the house with far more accuracy and budget than the practitioner performed for their modest fee. Disclosure lawsuits typically allege fraud, negligence, and misrepresentation against named defendants involved in the transaction. The practitioner must answer the complaint or be found liable by default of all the allegations. He must always hire an attorney to defend his position. Usually, after two years of hearings, depositions and court room appearances, including a tremendous outlay of money for legal and expert fees, the case will either settle or go to trial. In most instances, the practitioner will settle and later be dismissed from the case with prejudice. However, Meehan (1981) points out that even when due diligence is practiced by the practitioner the court may rule differently.

Liability exposure regarding the performance of the RGE is usually managed by proposals, contracts, disclaimers and adherence to practices normally observed within industry. However, without an industry-recognized guideline, the practitioner is bereft of a strong, defensible position. The lack of a formulated scope of work, analytical scientific method, or data analysis to substantiate conclusions can undermine the practitioner's defense of their findings and recommendations.

Some of the most oft-cited omissions of geotechnical reports prepared by practitioners are indicated below:

- What the home buyer is expected to learn from the study,
- Identifying the geologic processes with potential for occurrence, and associated pre-hazard risks,
- Identifying the severity of the geologic hazards affecting the building,
- Determination of geologic impact relative to allowable limits for building movement,
- Determination of real-time ground activity,
- Determination of post-hazard, real-time geologic risk,
- Specifying recommendations to minimize risk,
- Commentary concerning certainty and confidence of the conclusions drawn from the evaluation, and

- Recommendation of additional studies to be performed of the more severe conditions observed at the property.

Only when the home buyer has learned of the property's risk can they make a knowledgeable decision regarding purchase. Failure to inform the home buyer of the risk may constitute a breach of the standard-of-care.

Caution is, therefore, warranted when bidding to perform an RGE for a homebuyer or when being interviewed by a Realtor® for the referral. Competition amongst practitioners in the RGE marketplace is fierce and induces temptation for disregarding recommended procedures outlined in the professional literature. There is also considerable pressure to "cooperate" with the Realtor® to enhance the likelihood of receiving future referrals. This tends to weaken the third-party relationship with the homebuyer. Further, deliberately minimizing the scope of work to exclude mandatory tasks for the purpose of charging lower fees for service usually precludes the possibility of performing a more comprehensive analysis and meaningful conclusion statement. In theory, the homebuyer is the client, not the Realtor® or the seller. Regardless of how the RGE is performed or what fee is charged the long-term liability rests with the practitioner, especially when fraud is involved.

Professional ethics obligate the practitioner place the public's interest first. This is echoed by numerous professional societies, governmental agencies, and state and local laws. The ASCE has stringent Code of Ethics canons that state practitioners "shall hold paramount the safety, health and welfare of the public...in the performance of their professional duties" (Hoke, 2016). Because, "the lives, safety, health and welfare of the general public are dependent upon engineering judgements, decisions and practices" (Hoke, 2016) that are incorporated into evaluating geologic hazards, and the geotechnical stability of buildings and their safety for occupancy. The practitioner is to inform the client, and other involved parties, of any serious danger from a geological hazard and its eminent affect to a house. Upholding ethical values gives greater credibility to the practitioner, their work product, and their reputation in the professional community.

7

APPLICATIONS AND PROCEDURES

Experienced practitioners generally develop or adopt proven methodologies that they employ while performing the RGE. However, one with little experience can benefit from an already proven methodology. The following introduces new applications and procedures, and briefly reiterates previously discussed information.

It is forensic engineering geology and geotechnical engineering that applies hazard-structure interaction to the RGE. The practitioner must rely upon empirical data from field observations, employ scientific principles, and use deductive reasoning to derive proper conclusions. Also, the practitioner must recognize professional limitations in capability and licensure jurisdictions and refer matters to the proper specialists (McGill, 1954). Shortcuts in this process may lead to misinterpretations. The method of data acquisition is left to the preference of the practitioner. It is not the intent of the RGE to instruct the practitioner on the procedures in obtaining the information, but rather to assure that the homebuyer is provided with meaningful information they are expected to learn.

The RGE relies upon several tasks that are essential to properly complete the conclusion statement (Chapter 3). These tasks are:

- Request a history of the property from the seller or seller's representative,

- Research city, county, state and federal geological agency publications,
- On-site inspection with the buyer or buyer's representative,
- Survey of cracks in the building and site improvements,
- Complete a floor level survey of the building by using either a manometer or auto-leveling laser level,
- Analyze and score the potential processes for occurrence and the on-site hazards affecting the house and site improvements. Determine the category of geologic impact to the house, evaluate ground activity of the lot, and score the post-hazard geologic risk,
- Propose recommendations to correct the geotechnical or structural problems with the lot or house, respectively, and
- Optional: Prepare a geotechnical report that presents the research, data, analysis and conclusions.

To develop an initial understanding of the property, a history should be obtained from the seller or the seller's Realtor®. Pertinent information includes:

- Constructed improvements to the property (including those without permits),
- The repair of damage to the building, or site improvements,
- Any homeowner insurance claims and/or insurance funded repairs that were filed/performed on the subject residence prior to its listing,

- The age of patch and paint on interior and exterior building walls, and
- The legal history of the property and whether past or current lawsuits have been filed or are pending for ground movement or construction defect issues.

Research is mandatory for a preliminary understanding of the general geotechnical characteristics of the area and site. The site should be accurately located on street maps, topographic maps, Google Earth®, and geologic maps from county, state and federal agencies. Review of documents at city or county building departments may provide specific information about site geology at the time of development. From this research, the processes common to the area and site are identified. All potential processes and their worst case scenarios should be evaluated. However, only the realistic potential for occurrence needs to be reported.

A comprehensive building inspection generally includes measurements, photographs, and descriptions of the impact indicators expressed throughout the building. Field notes, measurements and photographs are kept in the job file, especially if a report is not prepared for the buyer.

A crack survey of the building is required. Cracks are documented as to their classification (CCS), location (walls, ceilings, slabs and footings), dimension (separation and length) and the age of the paint or patch through which they occur. A special assessment should be performed for those cracks that have recurred through a patch to determine the cumulative crack separation and length. If not clearly evident, then the practitioner should interpolate the crack data for the analysis. A floor level survey of the residence is required for obtaining floor deflection data (i.e. angular distortion, differential displacement, maximum displacement and end-to-end differential displacement). Floor deflection is a primary indicator and an integral part of assessing geologic impact. The survey provides a benchmark on structural performance at a given date and time, which can be of enormous value in making future assessments. The final floor deflection values have a typical tolerance of plus-or-minus 1/4-inch. Only sophisticated instrumentation is used for its measurement. Commonly, a manometer is used; however, a robotic auto-leveling laser will also provide accurate measurements, but with a slightly wider tolerance. Rolling marbles, or the use of carpenter levels, digital levels or lasers without auto-leveling capabilities are not precision instruments and cannot provide accurate floor level measurements requiring a sufficiently low tolerance of error.

Floor deflection data, when used in conjunction with crack pattern data, are beneficial to identify the hazards affecting building performance. However, floor deflection only indicates location and extent of foundation displacement and does not necessarily reflect the hazard(s) responsible for the distortions. Crack patterns can provide supporting evidence for hazard identification. A crack pattern may suggest a single hazard. However, a number of crack patterns may suggest a variety of hazards. The hazards should be itemized, scored for severity, assigned to particular areas of distortion within the building, and assessed as either life-threatening or non-life-threatening.

Buildings may distort because of design, workmanship or material deficiencies, and not simply because of ground movement. This is typically termed “construction defect.” For instance, in raised-floor houses, should the span of floor girders between footings, or joists between girders be excessive, a floor sag effect may manifest, especially if dead or live loads are applied in weakly supported areas. A visual examination of the floor and foundation system below the house may reveal the source of the observed deflection. Also, lumber (whether green or dried) will shrink and/or expand with variations in humidity, or deflect under excessive loading, and create cracking in plaster walls. Further, cracks in concrete slabs may be initiated by concrete shrinkage, chemical attack, freeze–thaw internal expansion or cement-aggregate reaction. By evaluating all the primary and secondary indicator data the practitioner can assess the condition and rule out inapplicable causes and derive the actual cause. However, if there is uncertainty, then a professional structural engineer should evaluate the condition.

The practitioner should be aware that homeowners can unwittingly exacerbate certain hazards that impact their homes. Such is the case when the homeowner over irrigates, fails to maintain effective drainage on the property, or fails to perform a timely plumbing pipe repair. Many processes (i.e. expansive and collapsible soils) are water sensitive and may develop into hazards which affect building performance (Silvestri and Bouhemhem, 1995). This phenomenon is known as “homeowner-induced geologic impact” (Audell and Baghoomian, 1996) and should be evaluated by the practitioner.

The empirical and qualitative levels of evaluation have inherent limitations because destructive testing is not usually within the scope of these types of studies. Should the building walls be freshly painted, the slabs floated or replaced, or doors and window frames replaced or re-squared, then such repairs would alter the analysis and outcome of the conclusion statement. For instance, a seller may unintentionally conceal impact indicators in order to make the house more attractive to a buyer. However, if these repairs are unknown and not considered in the analysis of geologic impact and ground activity, then the certainty and confidence of the RES score may be compromised.

The practitioner, as an expert witness, may have the opportunity to perform destructive testing within the house. This may involve the removal of surficial materials to expose underlying damage. Documentation requires photography and mapping. For studying wall cracks, exhumation is necessary. The author's preferred method is: 1) Select a crack at a door or window frame corner that displays eccentricity; 2) Photograph the original crack to document its character; 3) Use very fine sand paper to carefully remove the first layer of paint from a wide area surrounding the crack; 4) Label the original layer of paint as L1, then photograph the area. Observe if the crack separation in the underlying layer of paint has become wider or if a patching material is present; 5) Remove the second layer of paint, and label it L2. Keep the second layer margin within the circumference of the original layer. A ring-like appearance of the paint layers around the crack should become apparent. Note any change in crack appearance. Photograph the area. 6) Again, remove the underlying layer of paint and label it L3. If the crack has ever been repaired it will begin to show at L3. Photograph the area. 7) With continued exhumation, concentric rings of paint layers will circle the crack. Every layer is labeled. Eventually, the paper backing of the drywall board will emerge and the exposed crack will display its maximum extent of separation. Photograph the area. In many instances, the area of cracking will show the various colors of patching materials and the drywall tape (or mesh) that retains the patch in place. The various layers of paint are assigned specific periods of time representative of the different occupants of the property. If the seller patched and painted many cracks to conceal their presence, and did not disclose them to a buyer, it could be considered nondisclosure. A photograph of an exhumed NDTC-type wall crack is shown in Figure 23.

Distinguishing crack recurrence in an exterior plaster wall requires close examination of the patch or filler material used for the repair. Frequently, paint alone is used to fill a crack. Drying paint will often shrink into the crack leaving the separation open, but along some lengths bridges are formed where the paint has filled the separation. Paint bridges (Figure 24) are diagnostic and may indicate the recency of ground movement and subsequent building distortion. The presence of uncracked paint bridges usually indicates no distortion after painting, and a cracked paint bridge indicates either continuous or renewed distortion after painting. Knowing the age of the paint provides a time constraint for the determination of the latest episode of building distortion in general terms.

Figure 23. Exhumed drywall crack (NDTC) shows numerous paint layers and drywall backing. Exposed crack in drywall is roughly twice the separation as crack on surface. (Abbreviations: L-layer and D-drywall).

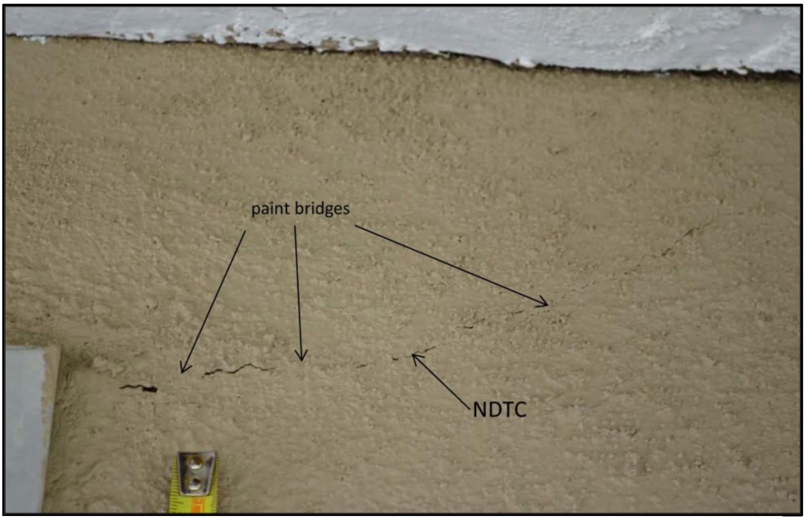


Figure 24. An NDTC-type wall crack in stucco with paint bridges.

A slab crack caused by concrete shrinkage is often improperly identified as a ground movement crack, and vice versa. These types of cracks in slabs are a common occurrence. However, distinguishing between the two, especially when separations are very narrow, is critically important when evaluating geologic impact. Concrete shrinkage is a necessary part of the hydration process. Water content and evaporation rate of the concrete can influence their development and cracks may occur within days or months following the concrete pour. Several different patterns will form of varying length, although most will be hairline separations that are very irregular and shallow in depth. Extreme shrinkage can generate cracks roughly 1/16 inch in separation and several feet in length. Crack growth will cease when the concrete has fully hardened. Ground movement stress on a slab will cause shrinkage cracks to initiate growth in their length, separation and depth. This process is called "overprinting" and the shrinkage crack then becomes a ground movement crack (Audell, 1996 and 2006). The change in crack character and supporting evidence from other ground movement indicators distinguishes slab shrinkage cracks from ground movement cracks.

For the evaluation of the structural condition of building materials the ASCE Standard 11-99 (2000) should be consulted. This guideline is an excellent resource for material standards and test methods, evaluation procedures, and report preparation. It is also congruent with this RGE guideline.

Geologic impact is different from the structural integrity of a building. Even though impact and structural integrity are directly related because all buildings are influenced by ground movement, they are still different aspects in the depiction of building stability. Impact is a measure of the severity of a hazard's effect to a building, whereas structural integrity reflects the building's resistance to distortion. In general, impact will diminish the structural integrity of a building over time. Buildings are resistant to the early exposure to certain hazards. However, they will eventually succumb and distort with continued ground movement.

Several factors lead to a stable building. As reported by Scullin (1983) these factors include administrating proper grading and building codes, plan check and review of designs, proper grading and building practices, and special inspections to assure construction compliance to design recommendations. Compromise of any of these factors can lead to ground movement and subsequent building distress.

8

CASE HISTORY

Introduction

Case histories are a vital element to the geotechnical sciences and constitute an essential learning tool for advancing the technology and improving the standard-of-care. For this reason, professional consultants, companies, societies and organizations encourage publication of case histories, because of the importance of exposing the errors made by others and presenting solutions to prevent their recurrence. In most instances, errors result from insufficient or omitted data, unknown site conditions, inadequate analysis, unsubstantiated conclusions, misjudgment and failure to adhere to a standard-of-care.

Most case histories in classic engineering geology are about either human-induced or natural hazard-induced geologic events which affect large facilities or regions. These cases include landslide-induced dam failures, regional fissuring from excessive groundwater withdrawal, and earthquake-induced building collapse, among others. However, cases of residential properties, as related to the RGE, typically result from errors and omissions as stated above. The consequent lawsuit becomes part of the case history.

A case is presented that involved a residential property (single-family residence) that was sold multiple times without adequate disclosure of geotechnical information which resulted in two lawsuits that were tried in the Superior Court of California, in Orange County. In the first lawsuit the author was retained as an expert witness, and in the second he was involved as a percipient witness.

This case relates to a distressed residence involved in a calamity of events that spanned nearly twenty years. Combined, this property had six owners, five sales transactions by three sellers, two disclosure lawsuits (*Johnson v. Shore*, 1995 and *Villar v. Coldwell Banker*, 2010), one legally contested transaction and cancellation of escrow, and one rescission of purchase. In both lawsuits the defendants included professional engineering geologists, real estate companies, and home sellers. Both lawsuits alleged fraud, negligent misrepresentation, and breach of fiduciary duty.

The information related to this lawsuit is public domain. In order to protect the anonymity of the parties involved, excluding the case names; the Realtors® and engineering geologist's names are withheld. This study presents the background information, building and lot description, geologic character, geotechnical data, analysis and conclusion statement, and a subjective editorial. Specific aspects of the property were taken from the author's files (Earthlogics, 1992; Geodynamics, 1996; and Geodynamics, 2002).

The main parties involved are the buyers as plaintiff, the buyer's real estate brokerage as defendant, the seller's real-estate brokerage as defendant, the professional engineering geologists as defendants, and the author as expert and percipient witness. This case history underscores the need for an RGE guideline.

These civil cases can be found on www.occourts.org. Downloading legal documents from the case listings requires a fee.

Background

The history of this case is very convoluted and involves a number of parties that move in and out of events that span nearly twenty years. A block flow-diagram (Figure 25) is provided to indicate the sequence of events that unfolded for this residential property.

This case dates back to 1981 when the original owner (O#1) purchased the property from the developer. O#1 performed an interior remodel and room addition in 1983. Because of severe building movement, O#1 abandoned the property in 1992. The bank (lender) foreclosed on the property and became owner (O#2).

The author, at the time doing business as Earthlogics Consultant Group, Inc., (ECG) was contracted by O#2 in 1992 to perform an RGE (ECG, 1992). This report indicated that the house had undergone “major to unallowable” structural settlement caused by a “high risk” ground subsidence condition. Also, ECG’s report provided a recommendation to construct a deep foundation system to stabilize the house in addition to other repairs.

In 1993, the property was sold below fair market value by O#2 and a real-estate company (RES #1) to buyer (B#3) with disclosure of the ECG report. B#3, now owner (O#3), remodeled the interior of the house. It was in 1994 that O#3, and another real-estate company (REC#2) sold the property to Johnson (B#4), who also employed REC#2, for full market value, and without disclosure of the ECG (1992) report. During the escrow inspection period, B#4 hired a professional engineering geologist, Practitioner #1 (1994), to examine the property. Practitioner #1 wrote a report which identified 6

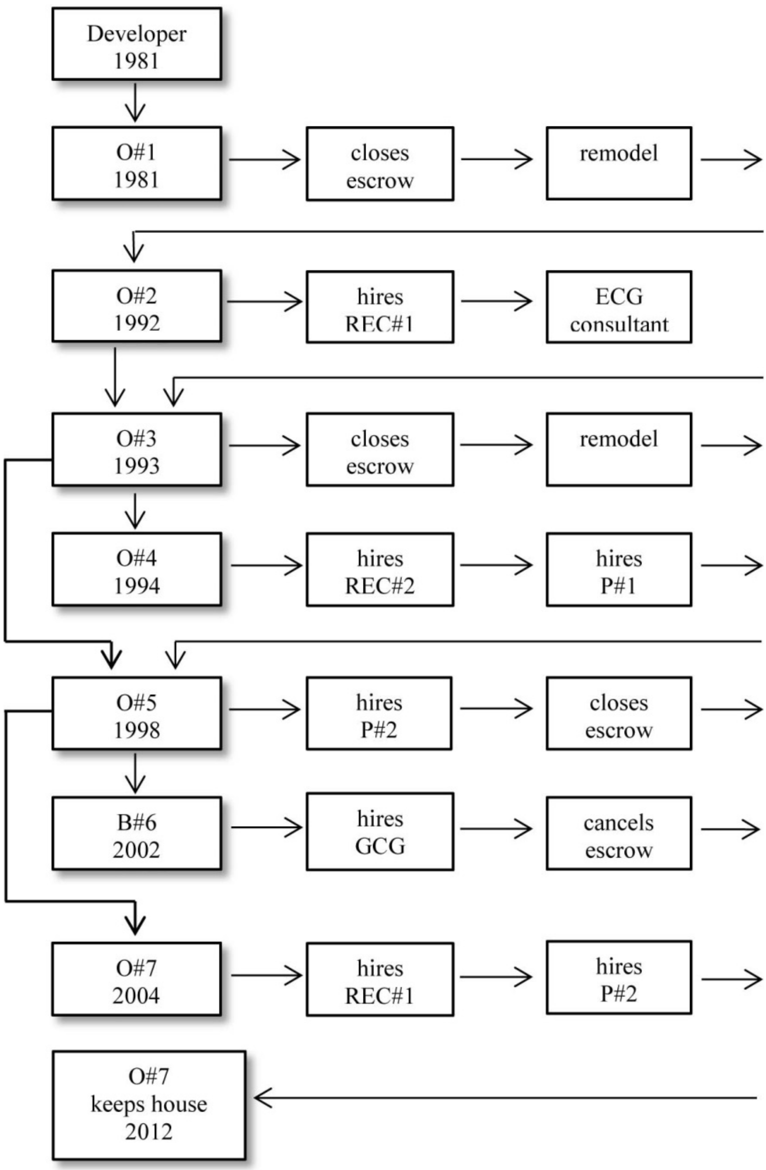
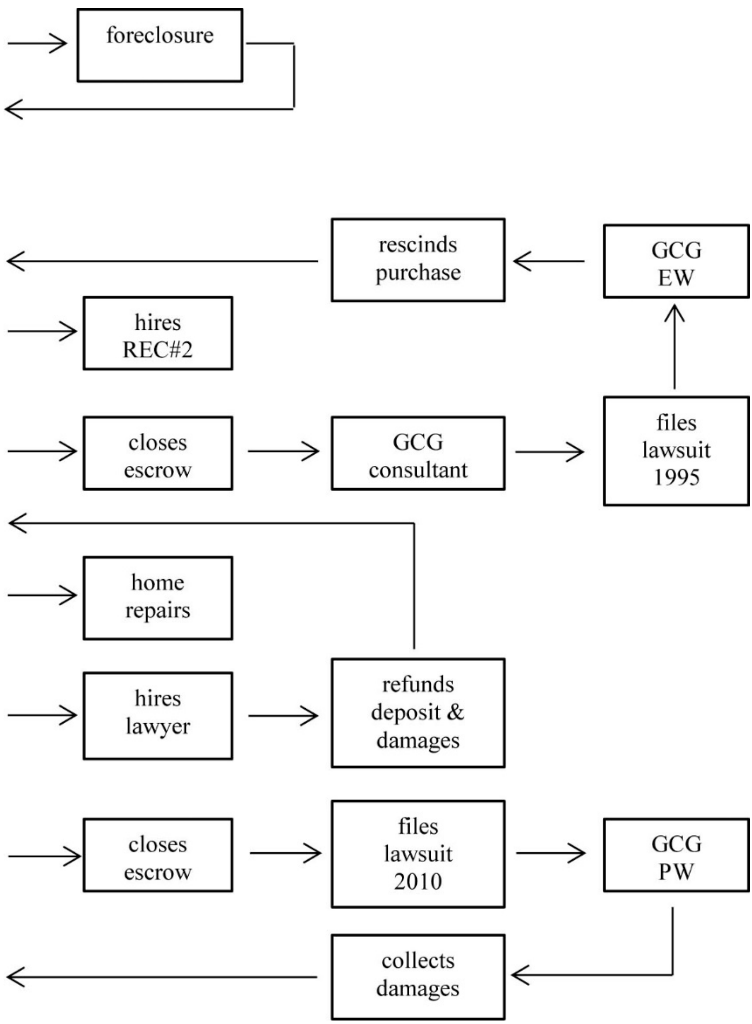


Figure 25. Block flow-diagram indicating the sequence of events for Case History.


foreclosure
rescinds purchase
GCG EW
hires REC#2
closes escrow
GCG consultant
files lawsuit 1995
home repairs
hires lawyer
refunds deposit & damages
closes escrow
files lawsuit 2010
GCG PW
collects damages

inches of building settlement, but did not discuss the geotechnical meaning or implications. B#4, now owner (O#4) was washing his car in the driveway when a neighbor approached and provided him with a copy of the ECG report. O#4 then contacted ECG in late 1994, the author now doing business as Geodynamics Consultant Group, Inc. (GCG), for a consultation, and learned of the property's geotechnical problems. O#4 immediately hired an attorney who filed a lawsuit against O#3, REC#2, and Practitioner #1. In 1995, GCG was retained as a plaintiff expert witness, as well as other experts in their respective fields. GCG and other experts identified the construction defect of O#3's remodel, the 6 inches of building settlement, and the deficiencies of Practitioner #1's report. This first lawsuit settled in 1996 and the court ordered O#3 to rescind the purchase. O#3, REC#2, and Practitioner #1 also paid attorney's fees, damages and expenses to O#4.

Owner #3 sold the property again in 1998 to another buyer (B#5), and provided insufficient disclosure of the prior lawsuit, and did not provide the ECG (1992) report or the information from the GCG (1996) study to the buyer. B#5 hired a different professional engineering geologist, Practitioner #2 (1998), during the escrow period to examine the property. Practitioner #2 prepared a report, but it omitted information regarding the 6 inches of building settlement. Escrow closed in 1998 and now B#5 is owner (O#5). The house continued to settle, and O#5 made several defective improvements to the building, including a new roof. O#5, in 2002, tried to sell the property to another buyer (B#6) for full market value. O#5 provided insufficient disclosure of the property's condition and the geological report from Practitioner #2. B#6 was in escrow and when walking through the house with a friend, became alerted to the pitched floors. Nearing the end of B#6's inspection period, she decided to have a third-party RGE of the property. Not knowing whom to contact, she found GCG in the phone book. During the phone consultation, B#6 learned of the property's geotechnical problems, and arranged for GCG to perform a Tier I RGE (verbal-walk through consultation with checklist report) (GCG, 2002). The GCG (2002) report discussed the 6 inches of building settlement and concluded that the property was of high to unallowable geologic risk. B#6 canceled escrow, but not without O#5 becoming disgruntled. Soon after, B#6 hired an attorney to recoup both the deposit on the house and other expenses incurred because of nondisclosure issues. In 2003, O#5 settled with B#6 out of court, but is still owner of the property.

Later in 2004, O#5 and REC#2 sold the property to Villar (B#7), who used REC#1, for full market value. By now O#5 was knowledgeable of the ECG (1992) report, Practitioner #1's (1994) report, the prior Johnson lawsuit (1995) and perhaps the accompanying GCG (1996) discovery study, Practitioner #2's (1998) report, the cancellation of escrow by B#6 and the accompanying GCG (2002) report. REC#2 was also aware of these studies because of prior lawsuits involving the property. O#5's disclosure to B#7 was late and again insufficient, but he only provided his geological report by Practitioner #2 (1998) and no others. With the close of escrow nearing, and with some suspicion, B#7 was convinced by REC#1 to rehire Practitioner #2 and perform an updated study. Practitioner #2's later report basically reiterated the findings of his original study. B#7, now owner (O#7), moved into the residence in 2005. It was not until much later in 2009 when O#7 detected the floor pitch, new cracks and other distortion indicators throughout the house. O#7's research subsequently discovered the legal history of the property and appurtenant documentation. O#7 filed a lawsuit in Superior Court of Orange County against REC#1 and other named parties, including Practitioner #2, in 2010. The complaint alleged fraud, negligence and misrepresentation. GCG was named a percipient witness. This second lawsuit settled in 2012 with all defendants, except for Practitioner #2 whom the court found liable of all charges.

Building and Lot Description

The subject property is located in the Beacon Hill residential development, in the City of Laguna Niguel, Orange County, California. This upscale tract development is situated in a rolling hillside area that was mass-graded and constructed in 1981. The subject residence is a 2,500-square-foot, two-story, wood framed house with exterior wood siding that is founded on a post-tensioned slab foundation. A room addition and interior remodel was performed in 1983 and another remodel in 1993. The lot consists of a level building pad and is situated at the end of a cul-de-sac. A rear yard 2:1 (H:V) manufactured slope about 60 feet high descends and transitions to an undisturbed slope that forms the north facing flank of a natural canyon. The house is set back roughly 20 feet from the top-of-slope. Neighboring homes exist at both sides of the subject property. Site improvements included concrete walks, patios and a driveway. Drainage was designed for forward flow to the street. A surface drain system was constructed around the building. The house lacked roof gutters.

Geologic Character

The pre-graded geologic character of the area surrounding, and including the property, consisted of many very large and deep, coalescing, ancient bedrock-landslides that overlie the Pliocene, marine-deposited, claystone member of the Capistrano Formation. Landslide deposits are typically translational-type, blocky, chaotic in structure, and slide along thin, shallow dipping, out-of-slope oriented clay seams. They are generally early Holocene in age. Bedrock is generally stiff, over-consolidated, mostly non-indurated, poorly bedded to massive, moderately jointed, olive brown where moderately to highly weathered and very dark gray where unoxidized. It is highly porous, has low permeability, very low shear strength when saturated, very expansive because of high montmorillonite (smectite) clay content, and rich in sulfate. Slopes are subject to creep, mudflow and landslide under moderate to heavy moisture conditions. The Unified Soil Classification System is CL to CH. Further, it is easily excavated with light earth-moving equipment and the removed clay material is compacted to create structural fill soil for building pads and slopes (Morton, et.al. 1974).

The general, as-grade character of the lot consists of a large fill-buttress overlying bedrock that retains the landslide deposits in place. The fill is wedge-shaped and deepens toward the rear of the lot. The approximate depth of fill soil below the front of the house is 30 feet and at the rear of the house it is 55 feet. At the top-of-slope the fill soil is roughly 65 feet deep. Some portion of the fill soil at the front of the house may overlie landslide deposits.

Geotechnical Data

Relative geotechnical data is taken from the author's technical reports (ECG, 1992 and GCG, 1996 and 2002). Data after 2002 are not available for this publication. GCG's last study of the property for buyer B#6 in 2002 documented the site conditions, and recent interior and exterior improvements, such as interior patching and painting, and a new roof sometime in 2000. The data used for the analysis has been extracted from prior ECG and GCG studies and does not represent the current condition of the house and lot at the time of this writing.

The physical character of the lot reflected a deferred maintenance condition. Drainage conditions surrounding the house were in poor condition, and although a drain system was present, the flowline gradients were altered and disturbed such that surface water ponded at many depressed locations surrounding the building. The exterior hardscape, including the driveway, was severely cracked, heaved, and laterally displaced. At the top-of-slope area, garden curbs restricted drainage, and were severely cracked and displaced. Soil at grade was very moist to wet reflecting a surficial groundwater condition because of over-irrigation and ineffective site drainage. Sulfate had corroded (pitting and spalling) the concrete at the front garage slab and along the perimeter house foundation system.

The rear yard descending slope displayed no evidence of landslides, however, a moderate slope creep and lateral-fill soil extension condition was apparent. Slope creep had laterally displaced hardscape at the top–of-slope, and a PPTG located between the driveway and garage slab indicated lateral-fill soil extension representing drift of the house/garage toward the rear yard slope.

The building interior showed extreme distortion. Interior walls displayed a variety of crack patterns indicative of a settlement condition. Cracks included CCS NVTC-1-, NDTC-, NVSC-, NHSC-, NHCC- and NDCC-types (see Table 2). In the foundation slab, RRTC- and ROTC-type cracks indicated initial heave followed by NPTC-type cracks indicating subsequent settlement. Footing cracks were typically NPTC-type. A manometer floor level survey indicated severe non-uniform flexural deflection from one side of the house to the other. The primary impact indicators and their dimensions are indicated in Table 11.

Many doors either swung open or closed in the direction of descending floor pitch and many door and window frames were out of square. Walls bowed toward the side of the house that had settled and wide ‘V’ gaps were found at many door and window frames throughout the house. The secondary impact indicators and their dimensions are indicated in Table 12.

Analysis and Conclusion Statement

The analysis of process pre-hazard risk, hazard severity, geologic impact to the building, the rate of ground activity, and finally the RES score of geologic risk has been performed, and is shown in Figures 26 through 33. The summary five-part conclusion statement is indicated below. This information reflects site conditions as they were in 2002.

Table 11. Primary indicator data for RGE Case History.

PRIMARY INDICATOR DATA			
INDICATOR	CRACK TYPE (CCS)	DIMENSION (in)	ALLOWABLE LIMITS (in)
Wall cracks in 2 year old patch and paint	NVTC-1	1/16 - 1/8	1/8
	NDTC	1/16	
	NVSC	1/32	
	NHSC	1/16	
	NHCC	5/8	
	NDCC	1/8	
Slab cracks (post-tensioned slab)	NPTC	1/16 - 1/2	1/8
	ROTC	3/32	
	RRTC	1/8	
Footing cracks	PVTG	3/8	1/8
	NVTC	1/32	
Floor deflection:			
Differential displacement (Δ)		6.3	2.0
Angular distortion (δ/l)		1/68	1/150
End-to-end displacement (ΔS)		6.3	2.0
Maximum displacement (ρ)		unknown	2.0

Table 12. Secondary indicator data for RGE Case History.

SECONDARY INDICATOR DATA		
INDICATOR	QUANTITY/ DIMENSION	ALLOWABLE LIMITS
Door swing	75%	75%
Door jam	75%	75%
Bowed walls	75%	75%
"V" gap at door/window frame	1/2 in	1/2 in

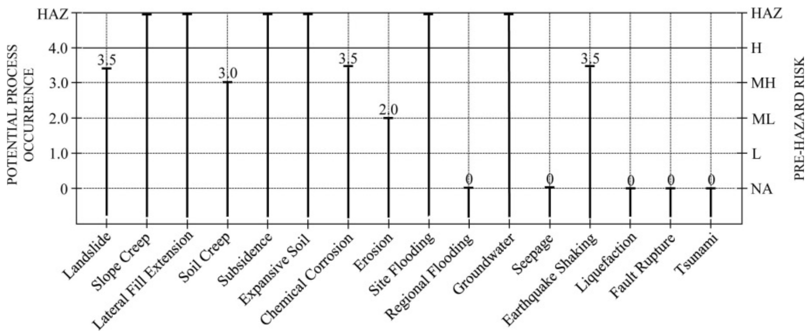


Figure 26. Potential occurrence and pre-hazard risk scores for Case History.

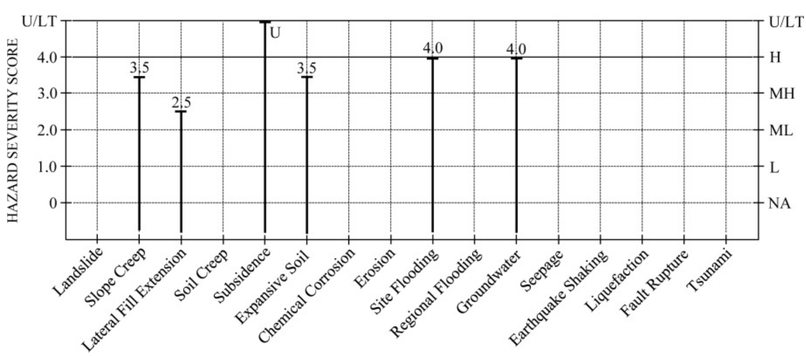


Figure 27. Severity scores of existing geologic hazards for Case History.

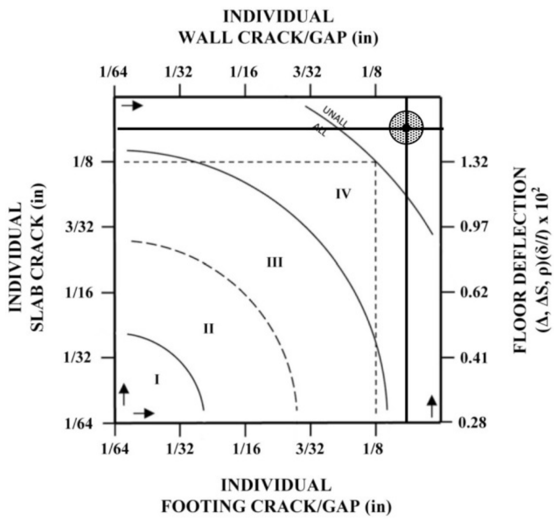


Figure 28. Determination of geologic impact based upon primary indicators for Case History. The level of geologic impact is Category V+.

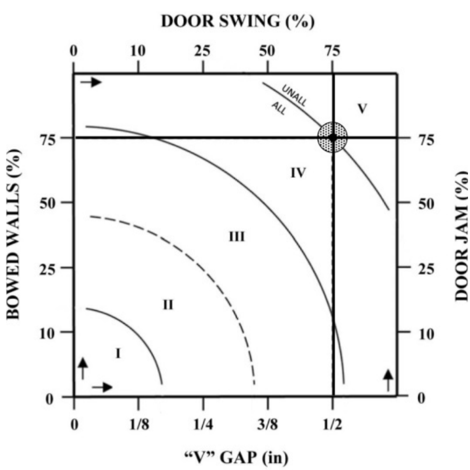


Figure 29. Determination of geologic impact based upon secondary indicators for Case History. The level of geologic impact is Category V.

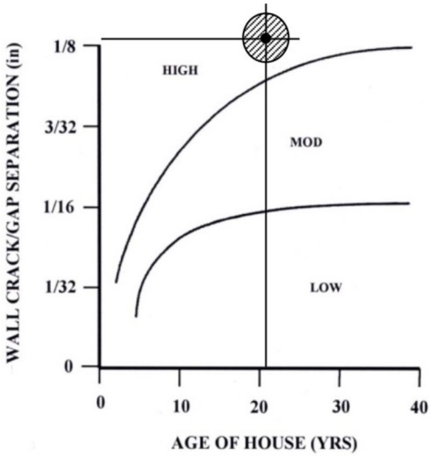


Figure 30. Determination of historic ground activity based upon dimension of wall cracks verses the age of the house for Case History. The level of historic ground activity is high.

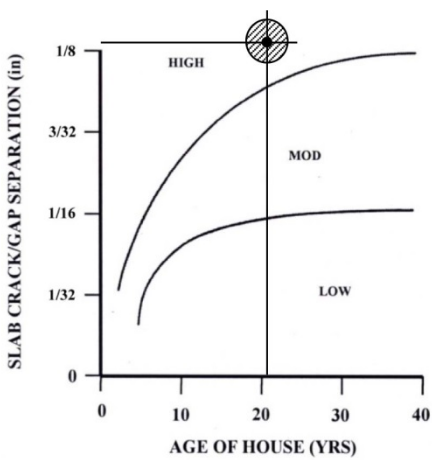


Figure 31. Determination of historic ground activity based upon dimension of slab cracks verses the age of the house for Case History. The level of historic ground activity is high.

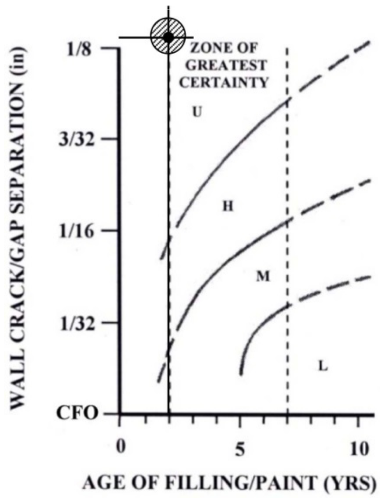


Figure 32. Determination of current ground activity based upon dimension of wall cracks verses the age of patch or paint for Case History. The level of current ground activity is unallowable.

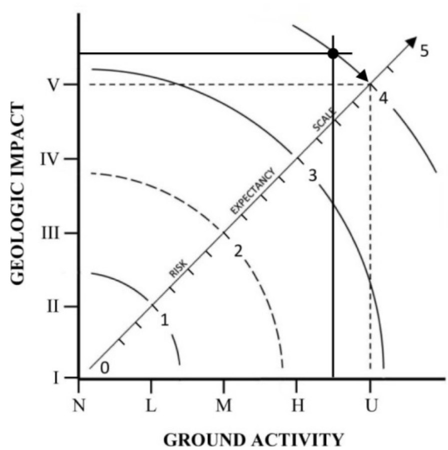


Figure 33. Determination of risk expectancy based upon the category of geologic impact verses the level of ground activity for Case History. The Risk Expectancy Score is 4.0.

Part 1-The geologic processes with potential for occurrence and pre-hazard risk that could affect the building and lot are individually scored. There are: landslides, slope creep, lateral-fill extension, subsidence, expansive clay, chemical (sulfate) corrosion, erosion, site flooding, groundwater, and earthquake shaking, Figure 26.

Part 2-The geologic hazards that affect the building are individually scored for their severity. These are: slope creep, lateral-fill extension, subsidence, expansive clay, chemical (sulfate) corrosion, site flooding, and groundwater. The dominant hazard is subsidence, Figure 27. None of these hazards are life-threatening.

Part 3-The level of real-time geologic impact to the building exceeds Category V, Figures 28 and 29.

Part 4-The rate of real-time ground activity from the hazards affecting the building is high to unallowable, Figures 30, 31 and 32.

Part 5-The RES score exceeds 4.0, which indicates the hazard(s) expectancy to impose additional impact to the building is unallowable, Figure 33.

Hazard-structure Interaction: Immediately following construction in 1981, expansive clay heaved the central foundation evidenced by the early formation of RRTC-type crack patterns in the slab. After roughly 5 years, following the remodel in 1983, ground subsidence initiated and became the dominant hazard. The building began to settle and pull-apart. Subsidence persisted for many years. In 1996 end-to-end foundation settlement was roughly 6.3 inches. Continued settlement was observed in 2002 based on the recurrence of NVTC-type crack patterns through two-year old patch and paint. In general, the cause of building settlement was initiated by fill-soil consolidation below the foundation triggered by introduction of excessive moisture from over-irrigation and ineffective site drainage. The competency of the compacted fill-soil below the building may have been a factor that contributed to the subsidence condition.

Certainty and Confidence: Good availability and quality of primary and secondary indicators. The level of certainty and confidence was high.

Safety for Occupancy: This house may be unsafe for occupancy, especially if subjected to strong ground shaking from an earthquake. It is very possible that because of the excessive distortion and pull-apart of the building framework, and overly stressed structural connections, compounded damage of weakened areas may occur. A structural engineer is required to verify the suitability of the building for occupancy.

Editorial

The Villar lawsuit illustrates how the post-transaction real estate transfer breaks down very quickly when professional engineering geologists fail to perform their respective duties and responsibilities. This lawsuit also exemplifies how sellers can manipulate sales transactions by withholding information.

In review of the legal documentation regarding this complicated case, it is apparent that there were several procedural failures by the Realtors® and both professional engineering geologists that led to the lawsuits. In each instance, both practitioners were the common fiber that held the fraudulent transactions together. Without their inconclusive reports, the transactions with Johnson (O#4), buyer B#6, and then Villar (O#7), would probably have not occurred. Their reports were used by sellers O#3 and O#5 to promote the fraudulent understanding that there were little to no geological or structural issues with the property. The Realtors® were complicit, fully aware of the problems, but denied both practitioners their knowledge of prior geotechnical studies, or even the prior lawsuit with Johnson, which clearly defined the concerns regarding the property. Regardless, a professional engineering geologist does not require the work of others to reach objective conclusions.

The practitioner's reports were alike, in that both failed to provide even the basic information of what a homebuyer is entitled to learn from a RGE. Both reports neglected to adequately evaluate the following: (1) the geologic processes and their pre-hazard risk to the property, (2) the severity of the hazards affecting the building and site improvements, (3) the level of geologic impact to the building and site improvements, (4) the rate of ground activity applicable to each hazard, and (5) the geologic risk to the building. Their cavalier approach to performing the RGE failed to place their client's interests first, and to hold paramount the protection of their health, safety and welfare.

9
SUMMARY

This book presents the geotechnical profession with guidelines for a systematic assessment and practical standard for performing the Residential Geotechnical Evaluation (RGE). It is also intended to benefit the home buyer because their decision-making ability is based on the geologic risk of the property they are considering for purchase.

There are many advantages to performing the RGE in accordance with published guidelines and standards. First, the practitioner's liability is reduced if the prescribed tasks are implemented. Second, it reduces the potential conflicts of interest engendered by the practitioner referral by the Realtor®. Third, it presents a clear, unbiased, and transparent understanding of the various geologic risks to all parties involved in the transaction. And forth, it brings to the practitioner's attention that they are to adhere to professional ethics of the profession by placing the client interests first, and to hold paramount the protection of their health, safety and welfare.

Although this guideline may not yet be considered a standard-of-practice until it gains greater acceptance in the engineering geology and geotechnical engineering communities, it can certainly be regarded as a standard-of-care, because it builds upon previously published work by authors in academia, governmental agencies, and the profession.

The RGE guideline contains five essential core points in the conclusion statement that are communicated to the home buyer: 1) The geologic processes that could affect the property, 2) The geologic hazards that currently affect the building and lot, 3) The category of geologic impact to the building, 4)

The rate of ground activity, and 5) The Risk Expectancy Scale (RES) score of real-time geologic risk to the building. This conclusion statement provides the necessary information for a more meaningful, consistent, and comprehensive RGE.

Other professionals, such as attorneys, building officials, appraisers, home inspectors and contractors may find some indirect use of this guideline. These professionals should recognize the limitations of this guideline if not used for the specific purpose of performing the RGE.

This publication contains technical information that may be difficult for the general public to understand. Any person that uses this guideline to perform an RGE other than a professional geologist or engineer may render inaccurate conclusions. The information, methods and procedures contained in this publication do not guarantee or warranty the safety for occupancy, geologic quality, or market value of any residential property.

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GLOSSARY OF TERMS

Acceptable: The subjective status of a condition that is considered satisfactory relative to general scientific or social views. It is based on the subjective opinions of an individual or a group.

Allowable: The objective status of a condition that is considered satisfactory relative to specific scientific standards, limitations or tolerances. It is based on established allowable limits as found in codes, ordinances or professional publications that are recognized by industry, academia, organizations or agencies.

Angular Distortion: The slab elevation differential of two points divided by the distance between those two points.

Architectural elements: Semi-permanent building elements that are non-bearing or load-transmitting, and typically include wood framing, drywall, door and window frames.

Category of geologic impact: A level of geologic impact to a building, such as Categories I, II, III, IV and V.

Cosmetic elements: Temporary or removable surficial building elements, and typically include floor tile, wood flooring, doors and windows.

Crack Classification System (CCS): A crack nomenclature and classification system. See Table 2 and Audell (2006).

Crack First Occurrence (CFO): The first occurrence of a crack in plaster, drywall, concrete or patching material.

Current ground activity (CGA): Specific rate of ground activity based on the occurrence of building cracks through paint or fill soil material of known age. It is defined within a narrow range of time that provides a real-time determination.

Differential displacement: The maximum difference in elevation between two end points located on the foundation.

Distortion: Displacement of a building element from its original constructed position. It is the eccentricity of a building impacted by ground movement. Distortion may be categorized by levels of geologic impact (see Category of geologic impact).

Eccentricity: Distortion of a building element or building from square, level or plumb, where stability may be influenced by gravity, ground activity, or redistributed building loads.

Engineering geology: The application of geologic principles to engineering practice. The study of geologic hazards and their influence to proposed construction or existing structures. It is practiced by a licensed professional geologist or engineering geologist. There is some academic and professional practice overlap with the field of geotechnical engineering.

Evaluation: An assessment of a condition relative to specific allowable standards. A geotechnical study entailing evaluation of geologic impact, ground activity and geologic risk.

Foundation displacement: Typically defined as two types, uniform and non-uniform. Uniform displacement occurs at the same rate throughout the foundation and non-uniform or differential displacement occurs at differing rates between various parts of the foundation. Factors controlling displacement are building loads and the underlying soil or rock conditions. It is typically differential displacement that results in structural damage.

Geotechnical: Pertains to the science of geotechnics. The application of geologic and engineering methods and principles to the acquisition and interpretation of soil and rock properties for the purpose of construction or hazard-impact-risk analyses of constructed buildings.

Geotechnical engineering: The field of engineering that deals with soil and rock properties, and their influence on design or construction of structures. It is practiced by a licensed professional engineer, geotechnical engineer, or geological engineer. There is some academic and professional practice overlap with the applied science of engineering geology.

Ground Activity: Relative rate of ground activity based on the occurrence or recurrence of a building crack through a constructed element such as a wall or slab of known age.

Hazard: A natural or human induced geologic condition or event that has caused damage, risk, loss of value to property, or affects the life, safety or welfare of the public.

Historic ground activity (HGA): Relative rate of ground activity based on the historic performance of buildings. Historic activity is determined by the dimension of separation of either a wall or slab crack relative to the age of the building. It is categorized as low, moderate and, high.

Impact: Severity of building distortion induced by some geologic hazard relative to a maximum allowable limit.

Inspection: An examination of a building condition. It is a compilation of observations or measurements of certain conditions within a building, however, lacks an interpretation of the data to a specific allowable standard to derive geologic impact, ground activity and geologic risk (see Evaluation for comparison).

Interpolation: The insertion of inferred data into an analysis based upon existing supporting evidence of other known data points.

Life-threatening hazard: Any geologic hazard with rapid onset, usually without sufficient warning, that would render a building unsafe for occupancy. These hazards typically include earthquake ground shaking, landslides, regional flooding, fault rupture, liquefaction, tsunamis, and volcanic eruption.

Maximum displacement: The maximum vertical difference between the lowest point elevation located anywhere on the floor and the original floor elevation.

Non-life-threatening hazard: Any geologic hazard with slow onset. Usually, these hazards would not render a building unsafe for occupancy. These hazards would include: soil expansion and shrinkage, subsidence, slope creep, erosion, and chemical corrosion.

Normal Diagonal Tension Crack (NDTC): A wall crack indicating foundation settlement. See Table 2.

Normal Horizontal Shear Crack (NHSC): A wall crack indicating foundation settlement. See Table 2.

Normal Oblique Tension Crack (NOTC): A slab crack indicating foundation settlement. See Table 2.

Normal Vertical Tension Crack-1 (NVTC-1): A wall crack indicating foundation settlement. See Table 2.

Post-hazard risk: The risk to a building after the occurrence of a hazard. It is the expectancy of additional building damage caused by a geologic hazard.

Pre-hazard risk: The risk to a building prior to the occurrence of a hazard. It is the vulnerability of a building to experience damage from a potential geologic process (hazard) (Varnes, 1984).

Primary indicator: A structural distortion indicator, such as a wall, slab or footing crack. Also applies to foundation displacement. It is used to determine the level of geologic impact to buildings.

Process: A naturally occurring geologic condition that does not present a risk to the life, safety or welfare of the public, or to the value of real property.

Pull-apart Oblique Tension Crack (POTC): A slab crack indicating foundation extension. See Table 2.

Pull-apart Parallel Tension Crack (PPTC): A slab crack indicating foundation extension. See Table 2.

Real-time: The processing of data such that the results are immediately available.

Residential Geotechnical Evaluation (RGE): An evaluation that determines geologic risk of a residential property.

Reverse Oblique Tension Crack (ROTC): A slab crack indicating foundation heave. See Table 2.

Reverse Parallel Tension Crack (RPTC): A slab crack indicating foundation heave. See Table 2.

Risk Expectancy: The expectancy of a building to become additionally damaged by an existing hazard(s).

Risk Expectancy Scale (RES): A numerical scale that scores the level of real-time geologic risk of a property. It is determined by the relationship of geologic impact relative to ground activity and is expressed as a score (from 0 to 5).

Secondary indicator: An architectural distortion indicator, such as doors that jam, doors that swing voluntarily, a door frame "V" gap, or bowed walls. It is used to determine the level of geologic impact to buildings

Seismic: Pertaining to an earthquake. The horizontal and vertical earth motions associated with earthquake ground shaking.

Seismic Diagonal Shear Crack (SDSC): A wall crack indicating foundation shaking by an earthquake. See Table 2.

Seismic Horizontal Shear Crack (SHSC): A wall crack indicating foundation shaking by an earthquake. See Table 2.

Seismic Vertical Shear Crack (SVSC): A wall crack indicating foundation shaking by an earthquake. See Table 2.

Standard-of-care: The level at which a prudent professional in good standing, having the same credentials and experience, practices in a similar community would perform under similar circumstances.

Standard-of-practice: An acceptable level of performance by a professional whose work product is based upon current scientific knowledge and expertise.

Structural elements: Any load-bearing or load-transmitting element in a permanent building that provides structural support. They typically include roof trusses, wall posts, floor girders, ceiling beams and foundations.

Superstructure: That part of the structure, or building, built above the foundation.

Vulnerability: The degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude.

ABBREVIATIONS

AEG: Association of Environmental & Engineering Geologists
ASCE: American Society of Civil Engineers
ASTM: American Society for Testing and Materials
ATC: Applied Technology Council
CBC: California Building Code
CBSC: California Building Standards Commission
CCS: Crack Classification System
CEG: Certified Engineering Geologist
CFO: Crack first occurrence
CGA: Current ground activity
ECG: Earthlogics Consultant Group, Inc.
FEMA: Federal Emergency Management Agency
GCG: Geodynamics Consultant Group, Inc.
GE: Professional Geotechnical Engineer
HGA: Historic ground activity
IBC: International Building Code
ICBO: International Conference of Building Officials
PE: Professional Engineer
PG: Professional Geologist
RES: Risk Expectancy Scale
RGE: Residential Geotechnical Evaluation
UBC: Uniform Building Code
UBSC: California Building Standards Commission
USACE: United States Army Corps of Engineers
USGS: U.S. Geological Survey
δ/l= Maximum angular (slope) distortion (from Skempton and MacDonald, 1956)

ABBREVIATIONS (Cont'd)

Δ= Maximum differential deflection (from Skempton and MacDonald, 1956)

ΔS= Maximum differential deflection between end points of *l* (typically end-to-end of building perimeter) (from Boone, 1996)

ρ= Maximum settlement from original level of foundation (from Skempton and MacDonald, 1956)

δ= Maximum vertical displacement (settlement or heave) (from Skempton and MacDonald, 1956)

l= Length of horizontal run (from Skempton and MacDonald, 1956)

APPENDIX A

REPORT GUIDELINE FOR THE RESIDENTIAL GEOTECHNICAL EVALUATION FOR OWNERSHIP TRANSFER

2nd Edition

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June 2016

INTRODUCTION

The purpose of this guide is to aid practitioners with the organization, layout and content necessary for a conclusive Residential Geotechnical Evaluation (RGE) for ownership transfer report. The guideline conforms to the foregoing paper "The Residential Geotechnical Evaluation for Ownership Transfer: A Risk Assessment Guideline." It has been kept brief, and in an outline form, in order to facilitate quick reference and rapid review. A disclaimer is provided that should accompany all RGE reposts.

The two types of reports that can be derived from this guide are the checklist or full-report. The checklist report accompanies a Tier II study which often includes the verbal walk-through with the homebuyer. Although the checklist may be the most popular with the homebuyer because it's least expense to produce, it may be more difficult for them to understand. A complex format and the brevity of information could discourage the homebuyer from reading the report. This situation can be managed by design and layout of the checklist. The full-report, which is more costly to produce, is easier for the homebuyer to understand and comprehend. If economically feasible a full-report should be prepared.

The audience of any RGE report is not only the general public, but also professionals in the geotechnical, legal, real estate and governmental sectors who may scrutinize and critique the report for its scientific methods, credibility, and conclusiveness.

CONTENTS

The sections of the RGE REPORT include the following:

1.0.0 EXECUTIVE SUMMARY

1.1.0 In a brief discussion present the five-point conclusion statement, hazard-impact-risk interpretation and recommendations for repair.

2.0.0 INTRODUCTION

2.1.0 PURPOSE

2.1.1 State the purpose of the study, what the home buyer is to learn, the dates the study was performed, and the persons present during the consultation. State that additional studies by other professionals such as civil, geotechnical and structural engineers, property inspectors and others, may be necessary.

2.2.0 SITE LOCATION

2.2.1 Describe where the site is located, name of the community, and the name of the City or County, and state.

2.2.2 Provide a street map which locates the site.

2.2.3 Provide the Assessor's Parcel Map and identify the lot. Provide the APN number and the legal description (lot and tract number, name of city or county, state)

2.3.0 SCOPE OF WORK

2.3.1 Describe the tasks performed for the study. The required tasks are: a) research of state and federal geological survey professional reports and maps; b) measurement and photo documentation of cracks in walls, slabs and footings; c) floor level survey by auto-leveling laser or manometer; d) geotechnical analysis, conclusions and recommendations according to the guideline method, and e) report preparation.

2.3.2 Describe those tasks that are not within the scope of work such as subsurface exploration, environmental assessment for the presence of hazardous substances (radon, asbestos, mold), physical inspection for construction or material defect or malfunction, endorsement of past or current construction of buildings or site improvements on or off the property, seller disclosure of geologic events or construction defects, design and construction drawings or cost estimates for repairs, prediction of future geologic events and their affect to the property or future stability of the residence and property.

2.4.0 BACKGROUND INFORMATION

2.4.1 Present the background information of the residence and lot, based on the research, field work and discussions with the seller and Realtors®.

2.4.2 Indicate the previous workers on the property and describe their involvement for the design and construction, and the year performed.

2.4.3 Indicate year lot or tract was graded and by which developer.

2.4.4 Indicate year house was built or age of house.

2.4.5 Briefly describe the house (e.g., number of levels, square footage, garage size and other characteristics).

2.4.6 Briefly describe the overall lot, indicate size (either by square footage or acreage).

2.4.7 Indicate the type of house construction (e.g., wood framed, exterior plaster wall finish, interior drywall finish, or other type).

2.4.8 Indicate the type of foundation system (e.g., grade slab, raised floor, continuous footing, isolated post footing, post-tension slab, caisson grade-beam, or specialty types).

2.4.9 Indicate the site improvements to the property (e.g., pool and spa, concrete walks, walls, patios, patio covers, and other improvements.).

2.4.10 Indicate the age of exterior and interior wall patching and painting, or year performed.

2.4.11 Indicate permits taken for the site improvements.

2.5.0 RESEARCH

2.5.1 At the municipal agency, review grading plans, tract maps, easement maps, seismic safety elements, California

Coastal Commission documents, if available, to determine the character and disposition of the lot. Also, review the building file for construction permits, prior geologic reports or engineering plans for construction, and any communications between the property owner and agency.

2.5.2 Review state and federal geological agency publications such as professional papers, regional geologic maps, seismic studies, landslide studies, and other applicable publications.

2.5.3 Review the state geological agency Seismic Hazard Zones maps for seismic-induced landslide or liquefaction potentials in the area and for the site, if such maps have been produced.

2.5.4 Review Federal Emergency Management Agency (FEMA) flood maps for regional flood potentials in sensitive areas, such as canyons, plains, washes, or coastal areas at or near sea level.

2.5.5 Review aerial images of the area and site on Google Earth® to provide a regional perspective.

2.5.6 Obtain a history of ownership from the property seller. This includes information on the latest date of patching and painting on the interior and exterior walls of the building, new construction, remodels, add-ons, presence of slab cracks below permanent flooring, repairs to the building that might not be readily observable (e.g., past pipe leaks in walls or below slabs), construction performed without permits, placement of fill soil on the lot, past geologic events (e.g., site flooding, interior water intrusion, landslides, or other conditions), past litigation, names of hired consultants or contractors, and outcomes of insurance claims.

2.5.7 Cite specific publications by the AEG, ASCE and other organizations that address the RGE, geologic hazards, the hazard-impact-structure interaction process, allowable settlements to buildings, limits for building distortion, and the life span of designed buildings. Many of these subjects and their respective publications are presented in the REFERENCE section of this guideline.

2.6.0 REFERENCES

2.6.1 Indicate the documents found at the municipal agency where the property is located.

2.6.2 Indicate the documents used for the preparation of the report.

2.6.3 Indicate documents by other geotechnical consulting companies which pertain to the property. If necessary, briefly annotate each reference.

2.6.4 Provide a list of the cited references at the end of the report.

3.0.0 SITE DESCRIPTION

3.0.1 Describe the layout of the lot and the location of the building on the lot.

3.0.2 Describe the lot and building pad (i.e. trend, lot shape, property line locations and other characteristics).

3.0.3 Identify slopes (e.g., location, height, ascending, descending, slope ratios, on or offsite from property lines, and other characteristics).

3.0.4 Describe the location of fill soil and fill soil depths below the building.

3.0.5 Identify the setbacks from property lines and the location of the building, pool, spa from the top of slope, toe of slope, and offsite features.
3.0.6 Identify the easements for municipal utilities, location and width.
3.0.7 Describe the general condition of the property and upkeep by the seller.
3.0.8 Describe the geomorphic character of the area where the lot is located (e.g., ridge top, canyon hillside, floodplain, terrace, or other characteristics).
3.0.9 Identify the topographic elevation of the lot or finish pad elevation above sea level, the name of the USGS quadrangle map where the property is located.
3.0.10 Provide a topographic map (a portion of the USGS quadrangle) which locates the site.
3.0.11 Describe the rough graded character of the lot (e.g., cut lot, fill lot, transition lot, graded on a natural slope, graded as a canyon fill, or other characteristics).
3.0.12 Describe the character of the fill configuration (e.g., fill-wedge, stabilization or buttress fill, uniform or variable depth, fill blanket over natural, bridging fill over transition contacts, direction of deepening, or other characteristics).
3.0.13 Describe site drainage characteristics (e.g., surface and subsurface systems): drainage systems (e.g., surface drains, terrace drains, French drains, subsurface drains, sump, roof gutters, or other devices), location of discharge (e.g., street or rear yard slope terrace drain), direction of drainage flow (i.e. forward, reverse, over-slope, off-site properties, etc.), type of drainage pattern (e.g., flowline, sheet flow, surface drain sys-

tem, or other patterns), adequacy and efficiency of site drainage (e.g., good, fair, poor).
3.0.14 Provide the rough and precise grading plan as a figure, if available.

4.0.0 FIELD STUDY
4.0.1 Site observation is required by the practitioner to ascertain the geotechnical condition of the lot and the physical condition of the building. This is usually performed in the presence of the buyer, seller or Realtors®.
4.0.2 Inspect, measure and document the surficial geologic character of the lot and those areas adjacent to the lot. Indicate soil and bedrock types with generalized descriptions and classifications. Note the potential for the occurrence of a geologic process or existing geologic hazards on the site.
4.0.3 Inspect, measure and document the building for primary geologic impact (distortion) indicators: a) cracks in walls, slabs, footings, and b) floor deflection (e.g., differential displacement (Δ), angular distortion or slope (δ/l) and maximum or end-to-end displacement (ΔS). Indicate the type of foundation displacement, either as heave, settlement or pull-apart, or combination of displacements. Crack measurements should have the accuracy of one-thirty second inch and floor deflection measurements of one-quarter inch (plus or minus). All cracks should be classified by the Crack Classification System (Audell, 2006).
4.04 Inspect, measure and document the building for secondary geologic impact (distortion) indicators: a) percentage of bowed walls, b) percentage of doors that swing voluntarily, c)

dimension of ‘V’ gaps at door and window frames, and d) percentage of doors that jam in their respective frames.
4.0.5 Inspect, measure and document non-geotechnical (e.g., structural) distortions to the buildings. In some instances, buildings will distort because of defective design and construction practices, material fatigue, eccentric loading and distortion, and other causes.

5.0.0 SITE ENGINEERING GEOLOGY
5.0.1 Describe the geotechnical characteristics of the site. Reference the source of the information or state that “where data are lacking typical geologic parameters representative to the area are presented.” Discuss location of past and current events of specific geologic hazards.
5.0.2 Describe surficial geologic units, soil and rock types that comprise the site.
5.0.3 Describe geologic unit in which the foundation is embedded.
5.0.4 Describe the geologic formation; indicate name and rock type.
5.0.5 Describe the stratigraphy of the geologic column.
5.0.6 Describe the geologic structure of the bedrock and whether it is a factor with respect to site stability.
5.0.7 Describe any landslides, indicate date, extent and repair of past landslides, ancient landslides, landslides on off-site adjacent slopes, and nearby “mega-landslides” to the site.
5.0.8 Describe clay-soil expansion and shrinkage properties. Indicate potential, occurrences and locations.

5.0.9 Describe soil or rock expansion from mineral crystallization (e.g., pyritic expansion). Indicate potential, occurrences and locations.

5.0.10 Describe slope creep, expected depth and lateral extent from the top-of-slope on the pad.

5.0.11 Describe any peat deposits, indicate depth below grade and lateral extent.

5.0.12 Describe liquefaction, indicate potentials or past events.

5.0.13 Describe soil chemistry (corrosivity), indicate soluble sulfates, soluble chlorides, and pH, if known or observed.

5.0.14 Describe soil compressibility, indicate surficial or deep subsidence, load consolidation, hydroconsolidation.

5.0.15 Describe lateral fill extension, indicate fill-wedge configuration and characteristics.

5.0.16 Describe name and location of faults, indicate if on-site or near-site, and whether active, potentially active, inactive, as defined by local jurisdictions.

5.0.17 Describe ground water condition, indicate location on the building pad, perched zones, springs or seepage at the slope surface, man-made temporary surficial ground water condition caused by over irrigation or ineffective site drainage.

5.0.18 Describe the location of site from nearest earthquake fault, indicate expected magnitudes, past earthquakes and damages to building.

5.0.19 Describe property exposure to storm waves or tsunami wave run-up.

6.0.0 GEOTECHNICAL EVALUATION

6.0.0 State that the scientific method used in evaluating the site conforms to the foregoing paper "The Residential Geotechnical Evaluation for Ownership Transfer: A Risk Assessment Guideline," (Audell, 2016) or another published guideline for performing the RGE.

6.1.0 Present the following points for assessment:

6.1.1 The geologic processes with potential for occurrence and relative score. Identify existing hazards. Itemize and discuss each process and its location, and the buildings vulnerable to damage. Assess pre-hazard risk for each potential process.

6.1.2 The geologic hazards that currently affect the building, site improvements and the lot. Identify non-life-threatening, unallowable and life-threatening hazards. Itemize and discuss each hazard and provide severity score, location, cause and trigger for occurrence, and damage effects.

6.1.3 The category of real-time geologic impact:

(a) The geologic impact based on primary impact indicators. Indicate wall crack dimensions; slab crack dimensions; floor level survey data (e.g., angular distortion or slope (δ/l), differential vertical displacement (Δ), differential vertical end-to-end displacement (ΔS), and maximum vertical displacement from the original floor level (ρ). Tabulate the data showing allowable limits of each impact indicator. Use Figure 9 (this paper) to determine category of geologic impact.

(b) The geologic impact based on secondary impact indicators. Indicate percentage of doors that swing voluntarily; percentage of bowed walls; percentage of doors that jam in frames; and dimension of 'V' gaps in door or window frames. Tabulate the data showing allowable limits of each impact indicator. Use Figure 10 (this paper) to determine category of geologic impact.

(c) Discuss hazard-impact-structure interaction. Determine the causative geologic hazards, and which are non-life-threatening and life-threatening. Determine the Category of geologic impact to the building. Determine the building's safety for occupancy.

6.1.4 The historic and current levels of ground activity. Determine historic ground activity using Figures 11 and 12, and current ground activity using Figure 13 (this paper).

6.1.5 The real-time level of geologic risk expectancy. Determine Risk Expectancy Scale score using Figure 14 (this paper).

7.0.0 RISK MANAGEMENT

7.0.1 Discuss risk management options for the reduction of ground activity. This would pertain to site stabilization, site grading, surface drainage systems, building drainage systems, irrigation systems, irrigation practices and types of landscaping.

8.0.0 CERTAINTY AND CONFIDENCE

8.0.1 Discuss certainty and confidence of the Conclusion Statement as indicated in Section 6.1.0. The level of certainty and confidence is based upon a best case situation where subsurface geotechnical characteristics (e.g., fill soil depth, fill soil compaction) and building elements (e.g., footings, slabs, walls, floor pitch, 'V' gaps) are exposed for observation or facts are known regarding these elements. The best case situation can be compromised by the unavailability of these elements for observation.

9.0.0 CONCLUSION

9.0.1 Summarize the assessment and present the five-point Conclusion Statement as indicated in Section 6.1.0.

10.0.0 RECOMMENDATIONS

10.0.1 Provide risk-based recommendations for improvement or repair to the lot or building. They should be appropriate and substantiated by the conclusions. Recommendations should be generalized and preliminary, and subject to additional study prior to finalization. Indicate if other professional disciplines are necessary for implementation, such as those services by engineering geologists, or geotechnical, civil, and structural engineers, or architects and landscape architects.

11.0.0 CLOSURE

11.0.1 Indicate that the "Residential Geotechnical Evaluation was prepared in conformance to the guideline used or referenced, and meets the level of care exercised by members of the profession currently practicing under similar conditions." The report is to be signed and sealed either by the following professional licensees: Geologist, Engineering Geologist, Civil Engineer, Geotechnical Engineer, or Geological Engineer.

12.0.0 DISCLAIMER

12.0.1 A disclaimer accompanies all reports and indicates the limitations of the study.

12.0.2 The “geotechnical firm (or Contractor)” has performed a limited Tier (I, II or III) study for the “homebuyer (Client).” The Contractor has evaluated the geologic processes, hazards, impact, ground activity, and real-time geologic risk of the building, site improvements and property, and provided a preliminary opinion as to our findings, conclusions and recommendations. Because of the limited scope of our evaluation (see SCOPE OF WORK), all possible geotechnical conditions **cannot** be noted, predicted or conveyed at a complete level of confidence or certainty. This evaluation **cannot** possibly identify; (a) intentionally (fraudulent) or unintentionally obscured, disguised or covered-up patent defects or conditions to the building and lot, and (b) latent geological conditions that may significantly impact future building performance. For this evaluation, the general geological character of the site was ascertained by utilizing practical visual and empirical methods made on the day and time the study was performed.

The Client following receipt of this report, has read, understood, agrees and concurs with the results of this study prior to the purchase of this residence. **This geologic report does not constitute a warranty, an insurance policy, or a guarantee of any kind.** In no way does this report necessarily agree or confirm or concur with the data, conclusions and recommendations derived by previous workers of this site or tract development. The Client is invited to contact our office regarding the content of this report and/or to schedule a personal consultation for clarification of this study.

The report reflects an observation of the lot and building at the time of the inspection. This evaluation is only valid for the specific client and for the time this study was performed. The report is not intended as: (a) an opinion of the geologic and building conditions of neighboring properties, (b) a certification of non-permitted or non-engineered graded, structural and architectural improvements or repairs, (c) a guide in re-negotiating the sales price of the property, or (d) construed as an opinion of the value of the property. The seller may or may not be required to repair deficiencies reflected in this report, and that determination should be made by the buyer, the seller, the respective Realtors®, and/or attorneys involved in the property transaction.

For other prospective buyers whom receive this report, these buyers should contact our office for authenticity verification of this report, a follow-up consultation that would indicate current site conditions. The Contractor shall not be responsible or liable to any uninformed prospective buyer whom irresponsibly ignores the content and limitations of this document and purchases the property without further inquiry into the conclusions of this report by either the Contractor or any other qualified geotechnical company or individual.

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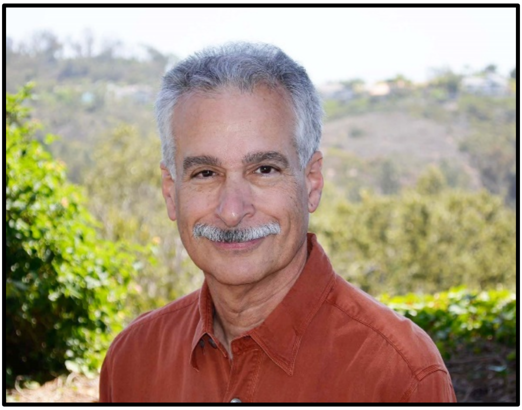

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Harry Audell is a resident of Laguna Niguel, California, and is a Consulting Professional Geologist and Engineering Geologist in the south Orange County area. He is the owner of Geodynamics Consultant Group, Inc. Mr. Audell is a Professional Geologist and Certified Engineering Geologist in Washington, and a Professional Geologist in Oregon, Arizona and Utah, as well as a Certified Professional Geologist through the American Institute of Professional Geologists. He earned his B.Sc. in Geology from the California State University at Northridge. He is a member of the Association of Environmental & Engineering Geologists, American Society of Civil Engineers, American Institute of Professional Geologists, and the Geological Society of America. He is the recipient of the prestigious Claire P. Holdredge Award and President's Award given by the Association of Environmental & Engineering Geologists. Mr. Audell is a forensic expert and has published many professional manuscripts on the subject of ground movement and its effect on buildings. His expertise is geologic hazard-impact-risk assessment as related to building distress. He is recognized by the geotechnical community because of his important contributions to the science of engineering geology and the subsequent benefit of this information to the general public.

HERMAN By Jim Unger By permission

"It's got a two-level finished basement."

GEOLOGIC RISK MATTERS!

This book provides to the Professional Geologist and Engineer a geotechnical guideline for performing the Residential Geotechnical Evaluation for ownership transfer. Once a homebuyer learns of the geologic risk of a residential property they can make the best decision based on the latest technology available.

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ISBN: 978-0-9897253-6-1