

AUDELL

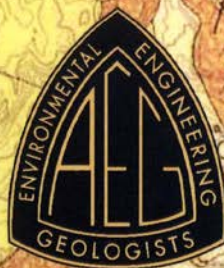
Field Guide to Crack Patterns in Buildings

Association of Environmental & Engineering Geologists

SP16

Field Guide to Crack Patterns in Buildings

A Guide to Evaluating Building
Cracks Caused By Geologic Hazards



Special Publication No. 16
ASSOCIATION OF ENVIRONMENTAL &
ENGINEERING GEOLOGISTS
Southern California Section

HARRY S. AUDELL

ON THE COVER: Geology of the San Juan Capistrano vicinity, Orange County, California. Map shows the Capistrano Formation (Tcs, in orange) and the 820 acre McCracken Landslide (Q1s, in yellow) (Morton and Miller, 1981). The Capistrano Formation is renowned for its problematic geologic processes and their interaction with developed residential properties.

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Field Guide to Crack Patterns in Buildings: A Guide For Evaluating Building Cracks Caused By Geologic Hazards

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DEDICATION

This book is dedicated to all professional geologists, engineers, architects, building inspectors, and contractors, who provide the highest quality workmanship and service to the general public by utilizing the latest technologies and scientific advancements available to the building industry.

PREFACE

Sooner or later every geologist, engineer, architect, building inspector, and contractor (i.e., practitioners of the building trade) realizes the need for information on building cracks and their meaning. Surely, cracks can be dismissed as an indication of ground movement conditions; however, upon closer examination, a practitioner can distinguish certain types of crack patterns that are helpful in defining a specific geologic cause for building movement. This field guide is an excellent tool for evaluating the geologic cause for cracking in most types of buildings. The guide does not discuss building cracks related to non-geologic processes.

Ground movement induces building distortion that manifests itself as cracks in plaster, drywall, and concrete materials. To better understand and communicate the relationship of soil-structure interactions by using crack patterns, a crack nomenclature and classification system has been developed for naming and describing cracks in walls and slabs. By using crack patterns, a practitioner can determine the sense of ground movement, the location of building impact, and the type of applied stress to buildings.

This book is based upon the original 1996 paper "Geotechnical Nomenclature and Classification System for Crack Patterns in Buildings" published in the *Journal of Environmental and Engineering Geosciences* by the Association of Environmental & Engineering Geologists. The "Crack Classification System" (CCS) was created from the need to understand ground movement-induced building cracks for use in the hazard-impact-risk assessment of developed residential and commercial properties. The CCS can also be used for preparing disclosure statements for property sellers, locating distressed areas within a building, and in forensic studies for litigation support.

The field guide is divided into five parts: part one discusses the introduction to the field guide which covers topics such as the classification system, references cited, and previous work. Part two introduces the crack nomenclature and the primary components for pattern identification. Part three provides twenty-nine crack pattern models, eighteen which are wall cracks and eleven which are slab cracks. Part four discusses crack origin and occurrence, patterns and growth, description, activity, overprinting, complexity, gaps and separation, and cracks not identified. Part five discusses application and relations of cracking and building performance. Part six briefly summarizes the text and suggests some practical uses for the field guide. Publications referenced throughout the text are listed in the References section of the book. All photographs were taken by the author.

The author realizes that some practitioners with little or no geology expertise will utilize the CCS in their work or to provide technical information to the general public. For the welfare of the public, it is better for these practitioners to realize the limits of their knowledge and obtain an opinion from a professional geologist if there is any uncertainty in the use or application of the CCS.

Finally, this book represents the third edition to the original book. For this book some updates to the crack models have been made and some new concepts are introduced regarding crack classification, interpretation, and character. Any questions, comments, or criticisms by the professional community are welcome and will be considered in following editions.

Harry S. Audell, PG
June 2006

ACKNOWLEDGEMENT

In 1991, while performing a geologic inspection of a residential property; my client mentioned, "...I know that's a crack, tell me what kind it is and what it means." I realized that simply identifying a crack without specifically conveying its geologic significance was a very unscientific approach to the interpretation of cracking. Since that time, I have studied and researched the wide assortment of crack patterns in various types of structures. In 1995 my friend and colleague, Richard J. Proctor, reviewed the first draft of my manuscript "Geotechnical Nomenclature and Classification System for Crack Patterns in Buildings" and suggested that it be submitted to the Association of Engineering Geologists (AEG) for publication. The paper debuted in 1996, and now after several years of ongoing refinement, this book has finally become a reality in making the geologic interpretation of crack patterns in buildings an easier task. The technical content of this book was peer reviewed by several colleagues who took the time and interest to critique draft manuscripts and provide valuable suggestions and commentary. Without their contributions, this book would not have been possible. Special recognition and gratitude goes to Richard J. Proctor, Roy J. Shlemon, PhD, Jeffrey R. Keaton, PhD, Howard A. "Buzz" Spellman, Eldon M. Gath, Tania Gonzalez and David C. Seymour. Also, I thank Professor Todd Fox, of the English Department at the California State University at Long Beach, for his editing of this manuscript. Finally, I thank my wife, Margaret S. Audell, M.D., for her unyielding patience and support.

CONTENTS

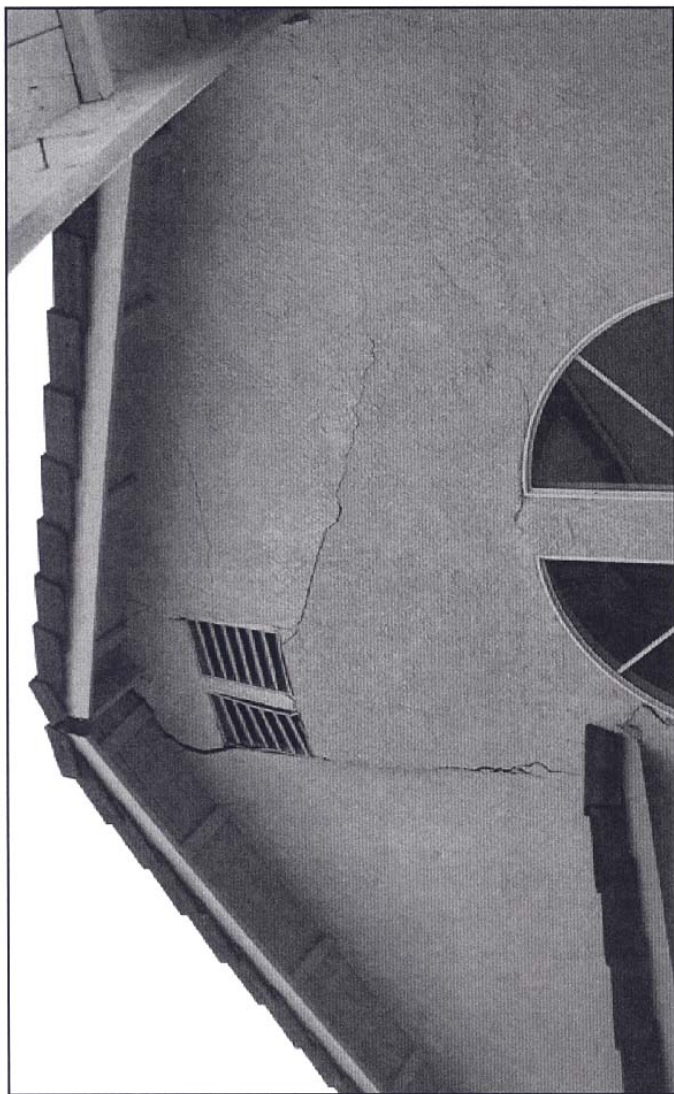
PART 1-INTRODUCTION	1
PART 2- NOMENCLATURE AND CLASSIFICATION SYSTEM	3
Introduction	3
Sense of Ground Movement	6
Wall Crack Orientation	6
Slab Crack Orientation	7
Type of Stress	7
Type of Feature	8
PART 3-CRACK MODELS	8
PART 4-CRACK CHARACTER	39
Origin, Cause and Occurrence	39
Lineaments, Growth and Trace	40
Description	43
Activity	48
Overprinting	49
Complexity	50
Gaps and Separations	52
Cracks Not Identified	55
PART 5-APPLICATION AND RELATIONSHIPS	55
PART 6-SUMMARY	62
REFERENCES	65
INDEX	71

FIGURES

- Figure 1: Crack classification system 4
- Figure 2: Crack nomenclature 5
- Figure 3.1-27: Sketch and photograph of crack models 9-37
- Figure 4: Crack description 44
- Figure 5: Relationship of floor deflection and the Normal Horizontal Shear Crack (NHSC) 47
- Figure 6: Determination of the level of ground movement 49
- Figure 7: Simple cracking 51
- Figure 8: Compound cracking 53
- Figure 9: Complex cracking 54
- Figure 10: Gap at floor slab and footing 56
- Figure 11: Crack map 60

TABLES

- Table 1: Index of crack models depicting the sense of ground movement and the type of cracks found in walls 38
- Table 2: Index of crack models depicting the sense of ground movement and the type of cracks found in slabs 39
- Table 3: Types of irregular crack traces commonly found in walls (plaster and drywall types) and slabs 42



Cracking in the exterior wall of a house located on the Via Belota Landslide in San Clemente, California (Photo by Audell, 2003).

Field Guide to Crack Patterns in Buildings

HARRY S. AUDELL

PART 1-INTRODUCTION

Crack patterns in exterior plaster walls, interior drywalled walls, and concrete slabs can aid in the determination of the geologic conditions responsible for ground movement and building distress. Cracks play a significant role in the assessment of building distress and they are important indicators that provide supporting evidence to any geotechnical study involving building movement. This field guide provides to the practitioner a versatile and systematic classification system for the description of ground movement-induced crack patterns in buildings. It does not discuss the occurrence of cracks in building materials related to non-geologic causes, such as material shrinkage, structural vibrations and others.

Crack models for eighteen patterns in walls and eleven patterns in floor slabs are described. They represent the most fundamental crack patterns upon which all cracks are based. The classification system (or integrated code sequence) is predicated upon the sense of ground movement, the crack

orientation, the type of stress, and the type of feature.

Ground movements are defined as normal (N), reverse (R), pull-apart (P), and seismic (S). Crack orientations in walls are defined as vertical (V), diagonal (D), and horizontal (H). Crack orientations in slabs are defined as oblique (O), parallel (P), and radial (R). The types of stress are defined as tension (T), compression (C), and shear (S). The type of feature may be a crack (C) or gap (G). For example, a wall crack pattern may be described as a "normal diagonal tension crack (Model NDTTC)." This nomenclature and classification system is referred to in this book as the "Crack Classification System" and by the abbreviation CCS.

Many publications have discussed problematic geologic hazards influencing buildings: Alfors and others (1973), Mathewson and others (1975, 1980 and 1982), Meehan and others (1975), Lytton and Dyke (1980), Robertson and Hollingsworth (1989), Hollingsworth and Grover (1992), Gath (1992), Nuhfer and others (1993), and Shlemon (1999). Still, other publications have discussed the structural behavior of buildings: Skempton and MacDonald (1956), Polshin and Tokar (1957), Bjerrum (1963), Grant and others (1974), Burland and Wroth (1975 and 1978), Wahls (1981), Boscardin and Cordina (1989), Rose (1989), Brown (1992), Boone (1996 and 2001), Day (1990, 1994, and 1998) and Nehdi (1998). Most of these studies clearly define the geologic processes related to ground movements, their effect on buildings, and the consequent induction of cracks. However, none were attentive to the diagnostic character of crack patterns and their relationship with geologic hazards.

The closest attempt to name crack patterns is provided by the American Concrete Institute (1994b) which describes three basic types that occur in slabs: diagonal, longitudinal, and transverse. These crack patterns are defined strictly as

CRACK PATTERNS IN BUILDINGS

stress acting on structural elements. Although these pattern designations describe a preferred orientation, they do not incorporate ground movement as causative factors for cracking. Wall cracks were not discussed.

An exhaustive attempt to find publications that specifically address a geotechnical nomenclature and classification system for describing specific crack patterns in walls and slabs was conducted by the author (Audell, 1996). The results of that research indicated that until 1996 such a system did not exist. This book presents an improved CCS based on ten years of additional study and refinement.

The CCS is the result of over 2,500 geological evaluations made on residential, commercial, and industrial buildings located on a variety of graded lot conditions and distinct geologic environments. Previous publications by the author (Audell, 1992, 1993, 1995, 1996, and 1999) have set the stage for this improved CCS. The described classification system has been successfully utilized by the author over a fifteen-year period and has proven to be a reliable tool.

It is not the purpose of this book to revisit technical geologic principles and stress-strain relationships of cracks in building materials, but rather to simply apply an integrated theory of ground movement-induced cracking in a manner understandable to technical and non-technical practitioners when evaluating building performance.

PART 2-NOMENCLATURE AND CLASSIFICATION SYSTEM

Introduction

Ground movement induces cracks in buildings that represent distortion caused by some geologic hazard. Because of their importance in understanding soil-structure interaction, they are classified by the CCS (Audell, 1996), Figure 1. The CCS

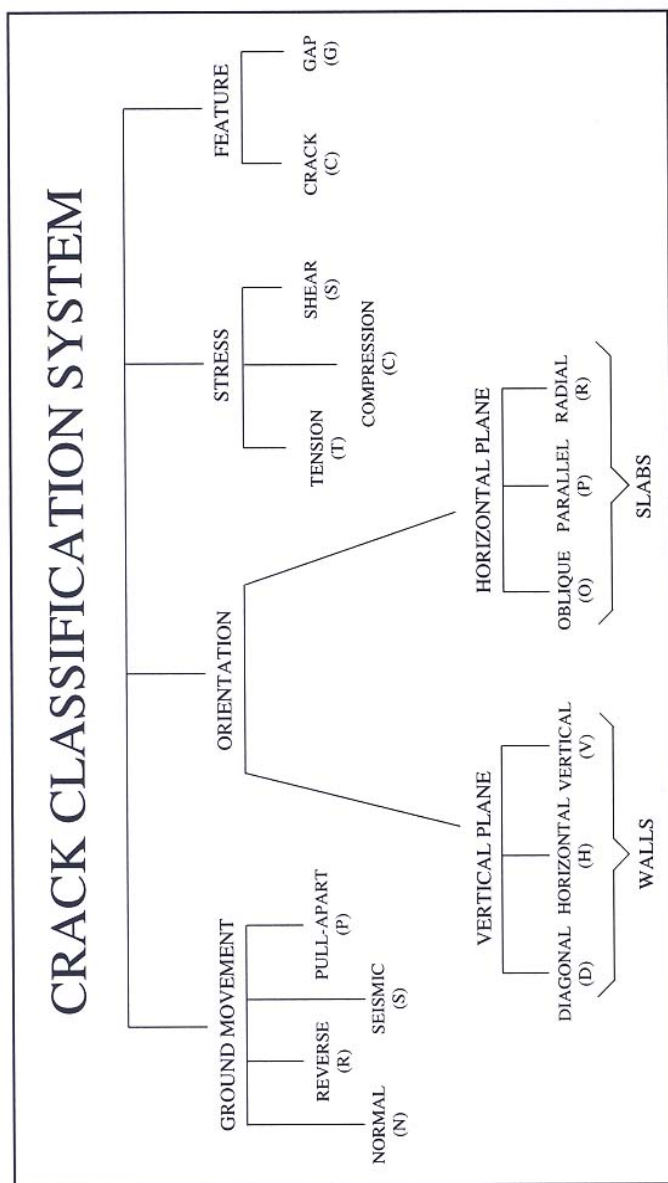


Figure 1. The "Crack Classification System" for classifying ground movement induced crack patterns in buildings (see text for application and definition of terms).

CRACK PATTERNS IN BUILDINGS

identifies and integrates four components for the nomenclature or code sequence. The first letter is reserved for the sense of ground movement, the second letter for the orientation, the third letter for the type of applied stress, and the fourth letter for the type of feature, Figure 2. The CCS can accurately name every type of crack observed within walls and floor slabs in most types of buildings.

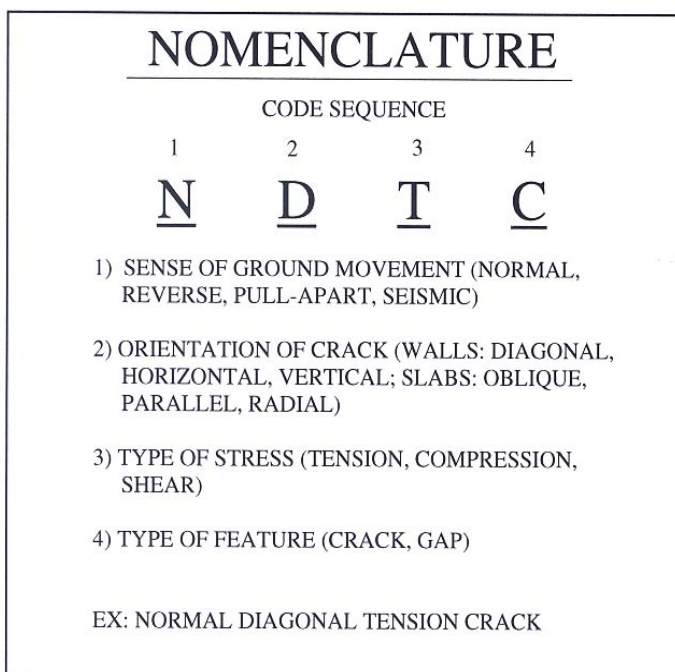


Figure 2. The "Crack Classification System" nomenclature (code sequence) for naming cracks.

Sense of Ground Movement

The most common types of geologic processes that may be hazardous and affect buildings are soil subsidence (including soil collapse, shrinkage, hydroconsolidation, and liquefaction), soil expansion, landslides, slope creep, lateral-fill extension, and earthquake induced ground shaking. These hazards translate into four senses of ground movement that cause cracking in walls and slabs. They are normal, reverse, pull-apart, and seismic, respectively. The first letter of the nomenclature code sequence is reserved for the "sense of ground movement."

Normal movement is the downward vertical motion of the ground surface caused by soil subsidence, shrinking expansive soil, and in most instances, landslides, and is designated by the letter "N." Reverse movement is the upward vertical heave from swelling expansive soil, and is designated by the letter "R." Pull-apart movement is horizontal lateral motion, which may be associated with landslides, slope creep, lateral-fill extension or soil creep from expansive soil, and is designated by the letter "P." The three senses of movement (normal, reverse, and pull-apart) may be realized by a fourth, earthquake (seismic) ground shaking, and is designated by the letter "S." A single geologic hazard or a combination of geologic hazards could affect localized or widespread areas throughout the building.

Wall Crack Orientation

Wall cracks oriented on the vertical plane are termed vertical, diagonal, and horizontal. The second letter of the nomenclature code sequence is reserved for the "wall crack orientation." Vertical cracks, typically found at mid-wall areas and oriented perpendicular to the foundation, are designated by the letter "V." Diagonal cracks, typically

CRACK PATTERNS IN BUILDINGS

found at the corner wall areas and oriented at some angle to the foundation, are designated by the letter "D." Horizontal cracks, typically found anywhere along the height of the wall and oriented parallel to the foundation, are designated by the letter "H." These cracks exhibit a preferred orientation because of the applied stress caused by ground movement.

Slab Crack Orientations

Slab cracks oriented on the horizontal plane are termed parallel, oblique, and radial. The second letter of the nomenclature code sequence is reserved for the "slab crack orientation." Parallel cracks, typically found near side-slab areas and oriented parallel to the foundation, are designated by the letter "P." Oblique cracks, typically found at the corners and center of slabs and oriented at some angle to the foundation, are designated by the letter "O." Radial cracks, typically found at the central portions of slabs are designated by the letter "R." Similar to walls cracks, slab cracks also exhibit a preferred orientation because of applied stress caused by ground movement.

Type of Stress

Cracks occur when a ground movement force induces a stress on a building material that exceeds the strength of the material itself. The types of induced stress potentials that occur in walls and slabs are known as tension, shear, and compression. The third letter of the nomenclature sequence is reserved for the "type of stress." Tension cracks are always found with open separations and are designated by the letter "T." Shear cracks are always found with slip displacement and sometimes with secondary stepover patterns across the crack are designated by the letter "S." Compression cracks are always found closed with

characteristic bulging or buckling are designated by the letter "C." Ground movement (aseismic) and seismic shaking can generate one or all three types of stress in buildings.

Type of Feature

The "type of feature(s)" that are observed in buildings are termed cracks and gaps. The fourth letter of the nomenclature system is reserved for either cracks or gaps. Cracks are designated by the letter "C" and gaps are designated by the letter "G." Cracks are breaks in building materials which include plaster, concrete, and drywall. Gaps are separations which develop at building element construction joints. Distinguishing a gap from a crack may require some knowledge of the building design and materials used in construction. Cracks in wood do not apply to this classification.

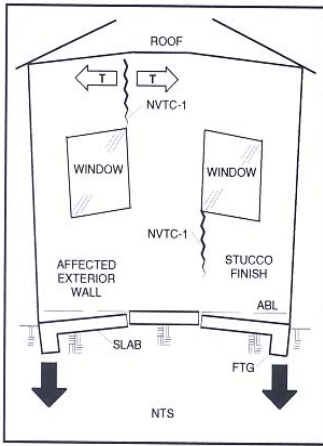
PART 3-CRACK MODELS

Wall crack models (Figures 3.1-3.18) comprise eighteen pattern variations, and slab crack models (Figures 3.19-3.29) comprise eleven pattern variations. An index of crack models depicting the sense of ground movement and the type of cracks found in walls and floor slabs is shown in Table 1 and Table 2, respectively.

Each model provides a sketch and photograph of a crack pattern. A description accompanies the model that identifies the sense of ground movement, orientation, stress type, and feature. Also, each model indicates the crack's character, occurrence, distinguishing features, and soil-structure interaction (i.e., geologic cause and building response). For each wall crack model, a corresponding slab crack pattern is presented, and for each slab crack model a corresponding wall crack pattern is presented.

CRACK PATTERNS IN BUILDINGS

MODEL NVTC-1 Normal Vertical Tension Crack-Type 1



Description:

Sense of Ground Movement: Normal.

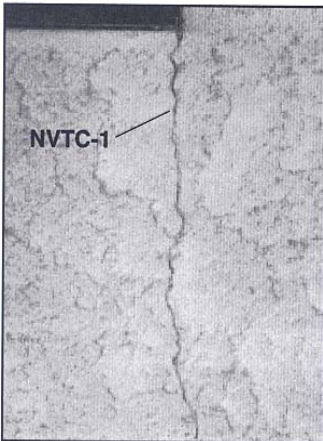
Orientation: Vertical.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; rough texture; singular propagation; terminal closure.

Occurrence: Common on exterior stucco walls and common on interior drywalled walls; found at top and center wall sections, mainly at door and window frame corners; interior drywall construction joints may control location of cracking.



Distinguishing Features: Linear trace; descending closure; differs from RVTC-2 (Fig. 3.4) by downward foundation displacement.

Soil-Structure Interaction: General soil subsidence, or possibly rotational landslide, causing downward displacement of opposite exterior foundation corners below the as-built line-of-reference (ABL).

Related Slab Cracks: NOTC (Fig. 3.19), NPTC (Fig. 3.22) and NRTC-1 (Fig. 3.26).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.1 Sketch and photograph of a Normal Vertical Tension Crack-Type 1 (NVTC-1).

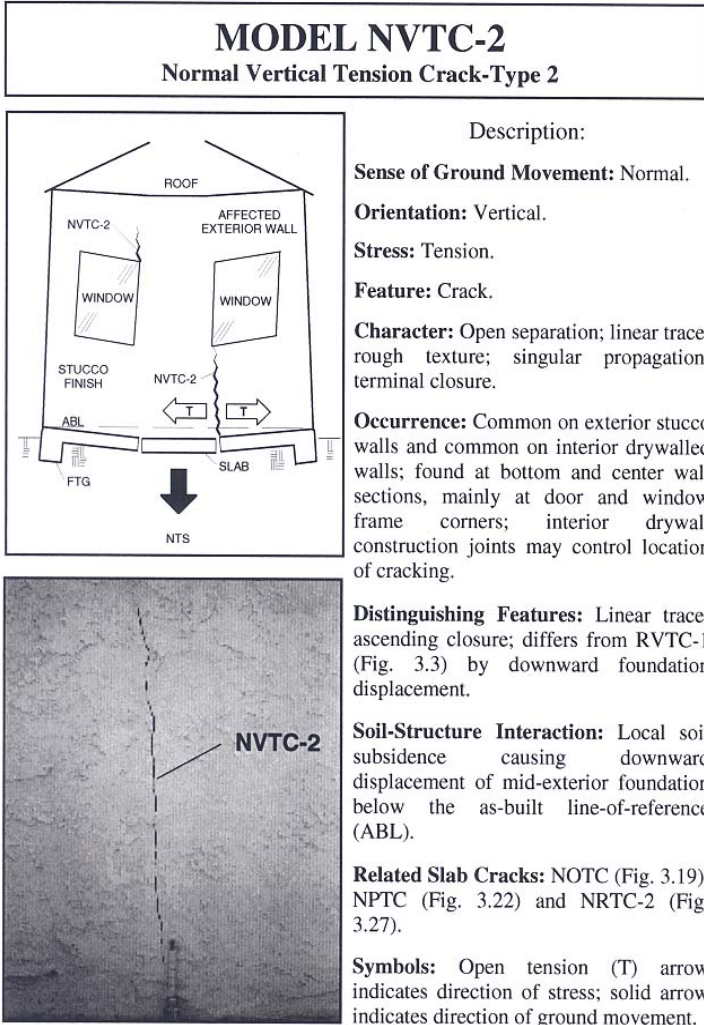
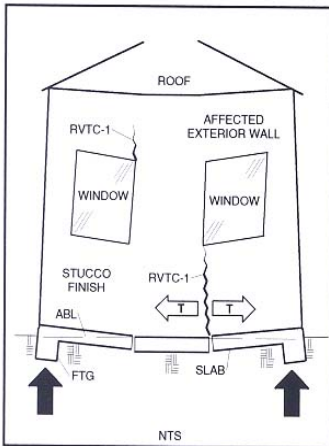


Figure 3.2 Sketch and photograph of a Normal Vertical Tension Crack-Type 2 (NVTC-2). Photograph highlighted for clarity.

CRACK PATTERNS IN BUILDINGS

MODEL RVTC-1

Reverse Vertical Tension Crack-Type 1



Description:

Sense of Ground Movement: Reverse.

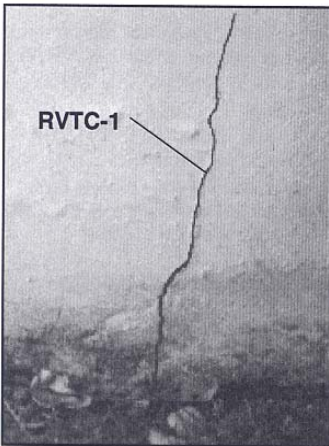
Orientation: Vertical.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; rough texture; singular propagation; terminal closure.

Occurrence: Common on exterior stucco walls and rare on interior drywalled walls; found at bottom and center wall sections; mainly at window frame corners; interior drywall construction joints may control location of cracking.



Distinguishing Features: Linear trace; ascending closure; differs from NVTC-2 (Fig. 3.2) by upward foundation displacement.

Soil-Structure Interaction: General soil heave causing upward displacement of opposite exterior foundation corners above the as-built line-of-reference (ABL).

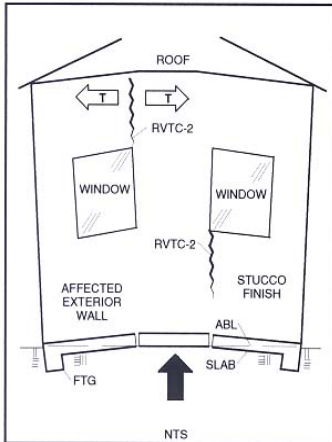
Related Slab Cracks: ROTC (Fig. 3.20), RPTC (Fig. 3.23) and RRTC-1 (Fig. 3.28).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.3 Sketch and photograph of a Reverse Vertical Tension Crack-Type 1 (RVTC-1). Photograph highlighted for clarity.

MODEL RVTC-2

Reverse Vertical Tension Crack-Type 2



Description:

Sense of Ground Movement: Reverse.

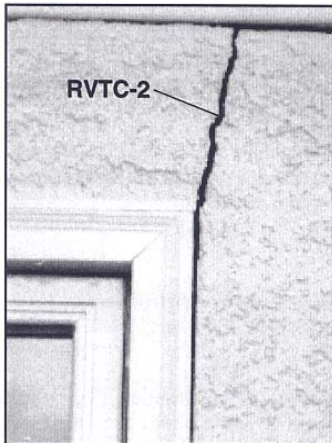
Orientation: Vertical.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; rough texture; singular propagation; terminal closure.

Occurrence: Common on exterior stucco walls and rare on interior drywalled walls; found at top and center wall sections, mainly at window frame corners; interior drywall construction joints may control location of cracking.



Distinguishing Features: Linear trace; descending closure; differs from NVTC-1 (Fig. 3.1) by upward mid-foundation displacement.

Soil-Structure Interaction: Local soil heave causing upward displacement of mid-exterior foundation above the as-built line-of-reference (ABL).

Related Slab Cracks: ROTC (Fig. 3.20), RPTC (Fig. 3.23) and RRTC-2 (Fig. 3.29).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.4 Sketch and photograph of a Reverse Vertical Tension Crack-Type 2 (RVTC-2).

CRACK PATTERNS IN BUILDINGS

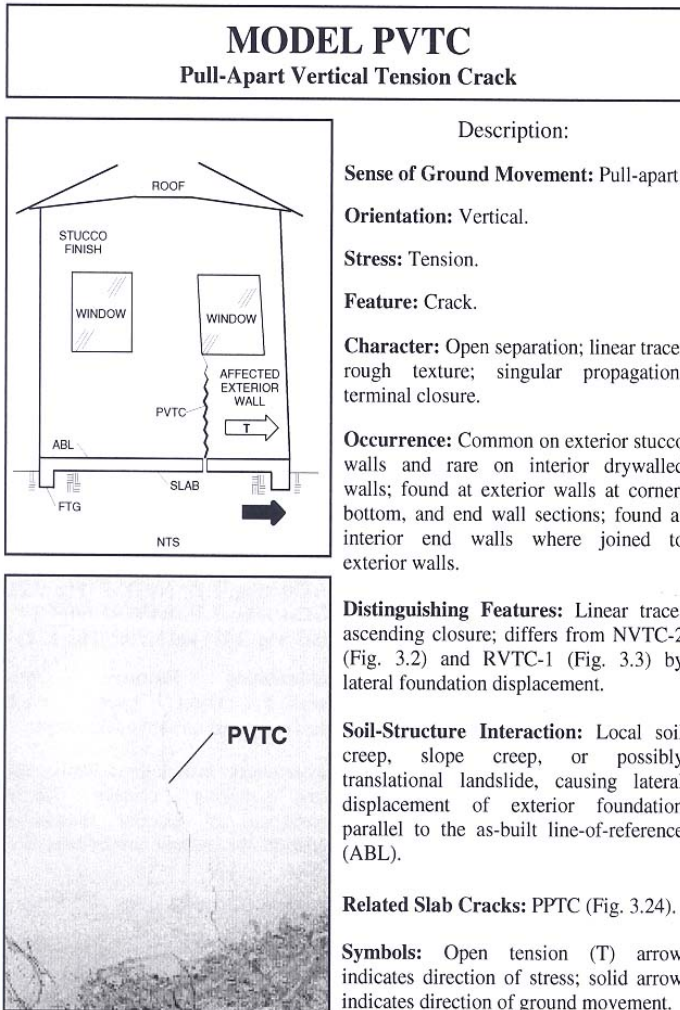
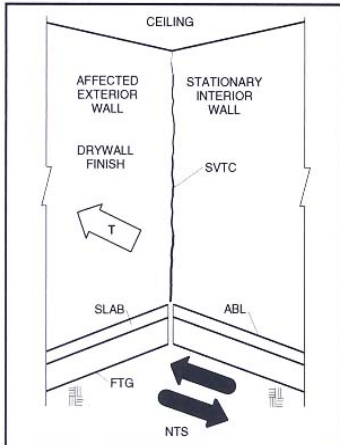


Figure 3.5 Sketch and photograph of a Pull-apart Vertical Tension Crack (PVTC).

MODEL SVTC

Seismic Vertical Tension Crack



Description:

Sense of Ground Movement: Seismic.

Orientation: Vertical.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; rough texture; singular or plural (convergent or divergent) propagation; terminal or bi-terminal closure.

Occurrence: Rare on exterior stucco walls and rare on interior drywalled walls; found at center and end wall sections, mainly at door and window frame corners; interior drywall construction joints may control location of cracking; may overprint on existing NVTC-1 (Fig. 3.1), NVTC-2 (Fig. 3.2), RVTC-1 (Fig. 3.3), RVTC-2 (Fig. 3.4), NVSC (Fig. 3.11) and RVSC (Fig. 3.12).

Distinguishing Features: Open separation; linear trace; found immediately after an earthquake event.

Soil-Structure Interaction: Earthquake ground shaking causing lateral displacement of exterior foundation parallel to the as-built line-of-reference (ABL).

Related Slab Cracks: SPTC (Fig. 3.25)

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

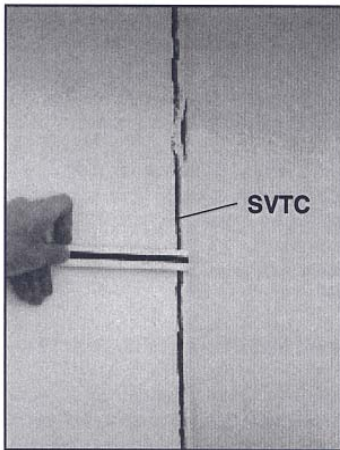
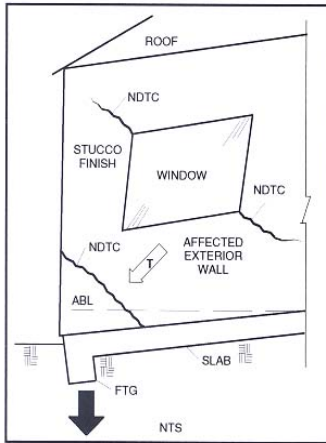


Figure 3.6 Sketch and photograph of a Seismic Vertical Tension Crack (SVTC).

MODEL NDTC

Normal Diagonal Tension Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Diagonal.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear and curvilinear trace; rough texture; singular or plural (divergent) propagation; terminal or bi-terminal closure.

Occurrence: Common on exterior stucco walls and common on interior drywalled walls; found at corner and end wall sections, mainly at door and window frame corners; rare at center wall sections; may form at terminus of NHSC (Fig. 3.13).

Distinguishing Features: Diagonal orientation; differs from RDTC (Fig. 3.8) by downward foundation displacement.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

Related Slab Cracks: NOTC (Fig. 3.19) and NPTC (Fig. 3.22).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

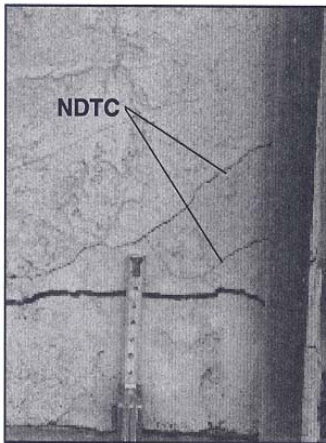
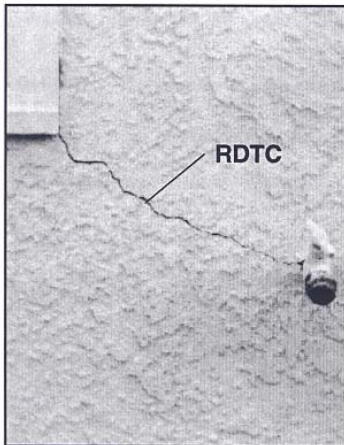
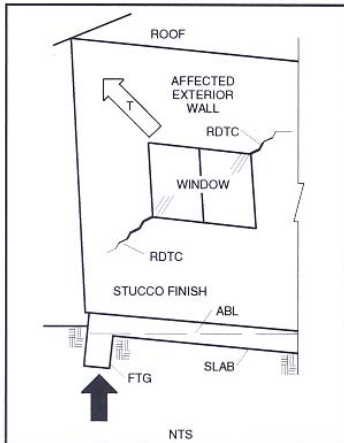


Figure 3.7 Sketch and photograph of a Normal Diagonal Tension Crack (NDTC).

MODEL RDTC

Reverse Diagonal Tension Crack



Description:

Sense of Ground Movement: Reverse.

Orientation: Diagonal.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear and curvilinear trace; rough texture; singular or plural (divergent) propagation; terminal or bi-terminal closure.

Occurrence: Common on exterior stucco walls and rare on interior drywalled walls; found at corner and end wall sections, mainly at door and window frame corners; rare at center wall sections; may form at terminus of RHSC (Fig. 3.12).

Distinguishing Features: Diagonal orientation; differs from NDTC (Fig. 3.7) by upward foundation displacement.

Soil-Structure Interaction: Local soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

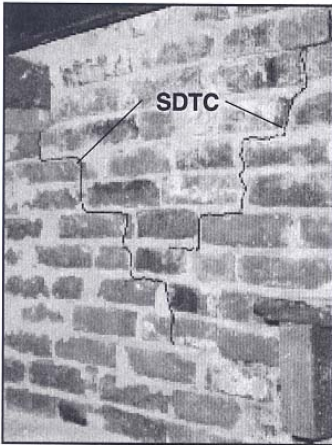
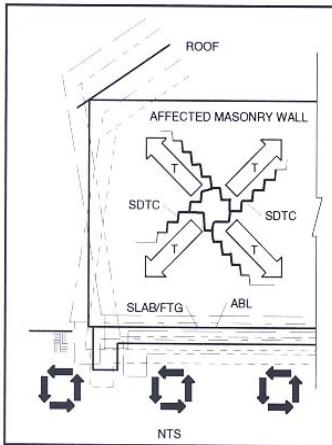
Related Slab Cracks: ROTC (Fig. 3.20) and RPTC (Fig. 3.23).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.8 Sketch and photograph of a Reverse Diagonal Tension Crack (RDTC).

CRACK PATTERNS IN BUILDINGS

MODEL SDTC Seismic Diagonal Tension Crack



Description:

Sense of Ground Movement: Seismic.

Orientation: Diagonal.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; stairstep pattern; rough texture; plural (divergent) propagation; bi-terminal closure.

Occurrence: Rare on exterior stucco and masonry walls, and rare on interior drywalled walls; found at center wall sections; mortar joints control location of cracks in masonry walls; may overprint on existing NDTC (Fig. 3.7); RDTC (Fig. 3.8) and NDCC (Fig. 3.17).

Distinguishing Features: Stairstep pattern; found immediately after an earthquake event.

Soil-Structure Interaction: Earthquake ground shaking causing simultaneous lateral and vertical displacement of foundation from the as-built line-of-reference (ABL).

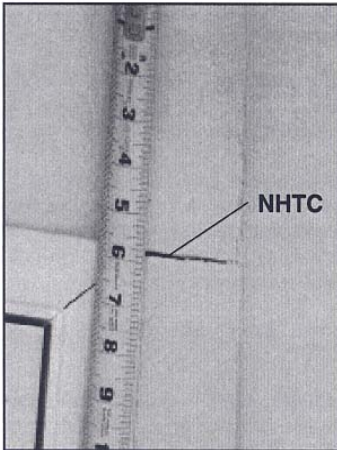
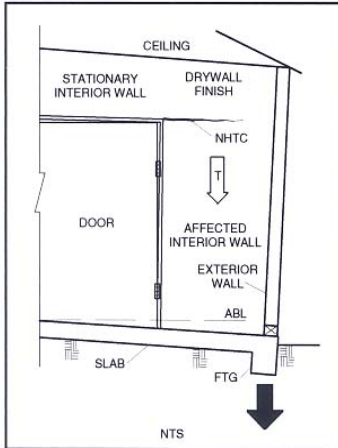
Related Slab Cracks: SOTC (Fig. 3.21) and SPTC (Fig. 3.25).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.9 Sketch and photograph of a Seismic Diagonal Tension Crack (SDTC). Photograph highlighted for clarity.

MODEL NHTC

Normal Horizontal Tension Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Horizontal.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear trace; smooth or rough texture; singular propagation; terminal closure.

Occurrence: Very rare on exterior stucco walls and rare on interior drywalled walls; found at corner and end wall sections, mainly at door and window frame corners and post and beam connections where joined to exterior walls; horizontal drywall joints on interior walls may control location of cracking.

Distinguishing Features: Open separation; linear trace.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

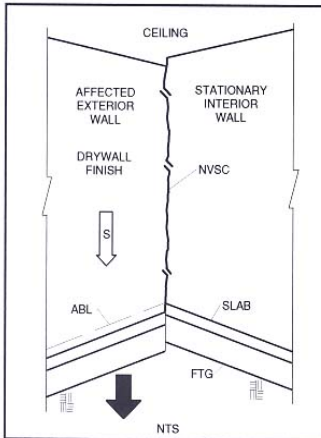
Related Slab Cracks: NOTC (Fig. 3.19) and NPTC (Fig. 3.22).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.10 Sketch and photograph of a Normal Horizontal Tension Crack (NHTC).

CRACK PATTERNS IN BUILDINGS

MODEL NVSC Normal Vertical Shear Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Vertical.

Stress: Shear.

Feature: Crack.

Character: Closed or very narrow separation; linear trace; smooth texture; singular or plural (divergent) propagation; parallel or total closure.

Occurrence: Very rare on exterior stucco walls and rare on interior drywalled walls; found at end wall sections, mainly at intersection of interior walls where joined to exterior walls; in drywall may exhibit abundant microscale stepover or moletrack pattern along crack length.

Distinguishing Features: Stepover and moletrack patterns.

Soil-Structure Interaction: Local soil subsidence, or possibly rotational landslide, causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

Related Slab Cracks: NOTC (Fig. 3.19) and NPTC (Fig. 3.22).

Symbols: Open shear (S) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

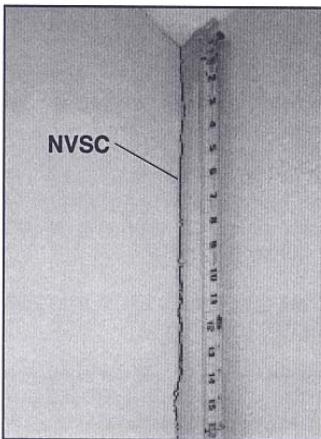
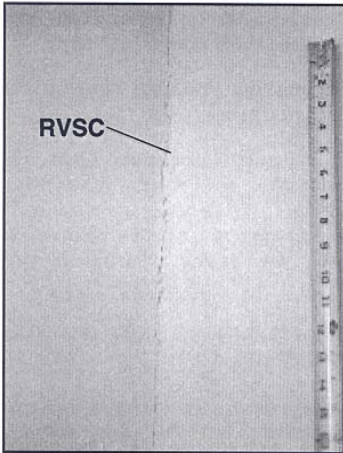
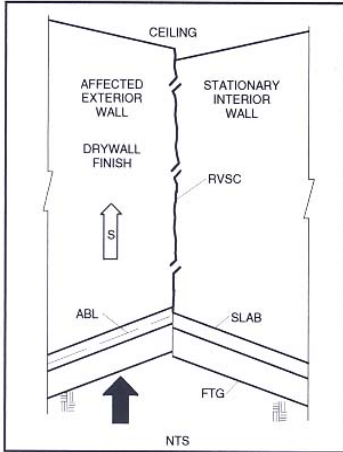


Figure 3.11 Sketch and photograph of a Normal Vertical Shear Crack (NVSC). Photograph highlighted for clarity.

MODEL RVSC

Reverse Vertical Shear Crack



Description:

Sense of Ground Movement: Reverse.

Orientation: Vertical.

Stress: Shear.

Feature: Crack.

Character: Closed or very narrow separation; linear trace; smooth texture; singular or plural (divergent) propagation; parallel or total closure.

Occurrence: Very rare on exterior stucco walls and rare on interior drywalled walls; found at end wall sections, mainly at intersection of interior walls where joined to exterior walls; in drywall may exhibit abundant microscale stepover or moletrack pattern along crack length.

Distinguishing Features: Stepover and moletrack patterns.

Soil-Structure Interaction: Local soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

Related Slab Cracks: ROTC (Fig. 3.20) and RPTC (Fig. 3.23).

Symbols: Open shear (S) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.12 Sketch and photograph of a Reverse Vertical Shear Crack (RVSC).

CRACK PATTERNS IN BUILDINGS

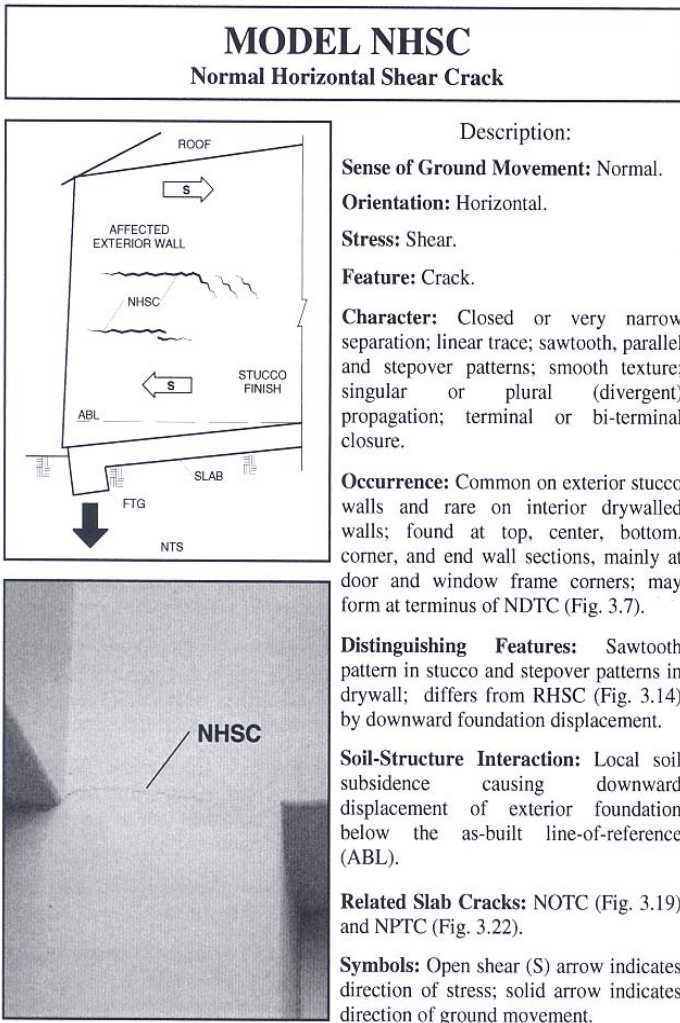
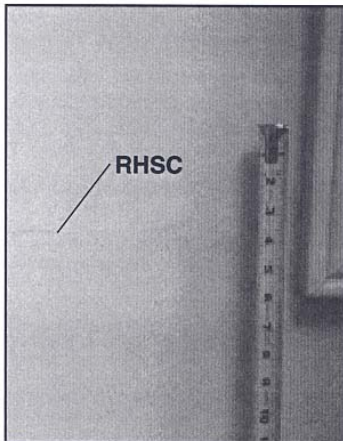
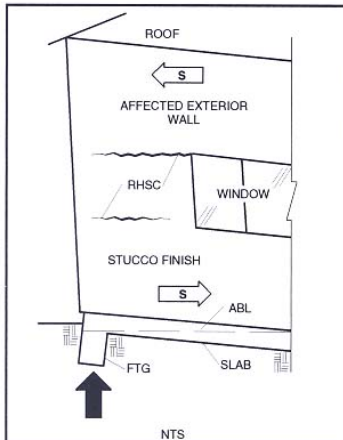


Figure 3.13 Sketch and photograph of a Normal Horizontal Shear Crack (NHSC).

MODEL RHSC

Reverse Horizontal Shear Crack



Description:

Sense of Ground Movement: Reverse.

Orientation: Horizontal.

Stress: Shear.

Feature: Crack.

Character: Closed or very narrow separation; linear trace; sawtooth, parallel and stepover patterns; smooth texture; singular or plural (divergent) propagation; terminal or bi-terminal closure.

Occurrence: Rare on exterior stucco walls and rare on interior drywalled walls; found at top, center, bottom, corner and end wall sections, mainly at door and window frame corners; may form at terminus of RDTC (Fig.3.8).

Distinguishing Features: Sawtooth pattern in stucco and stepover pattern in drywall; differs from HNSC (Fig. 3.13) by upward foundation displacement.

Soil-Structure Interaction: Local soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

Related Slab Cracks: ROTC (Fig. 3.20) and RPTC (Fig. 3.23).

Symbols: Open shear (S) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.14 Sketch and photograph of a Reverse Horizontal Shear Crack (RHSC).

CRACK PATTERNS IN BUILDINGS

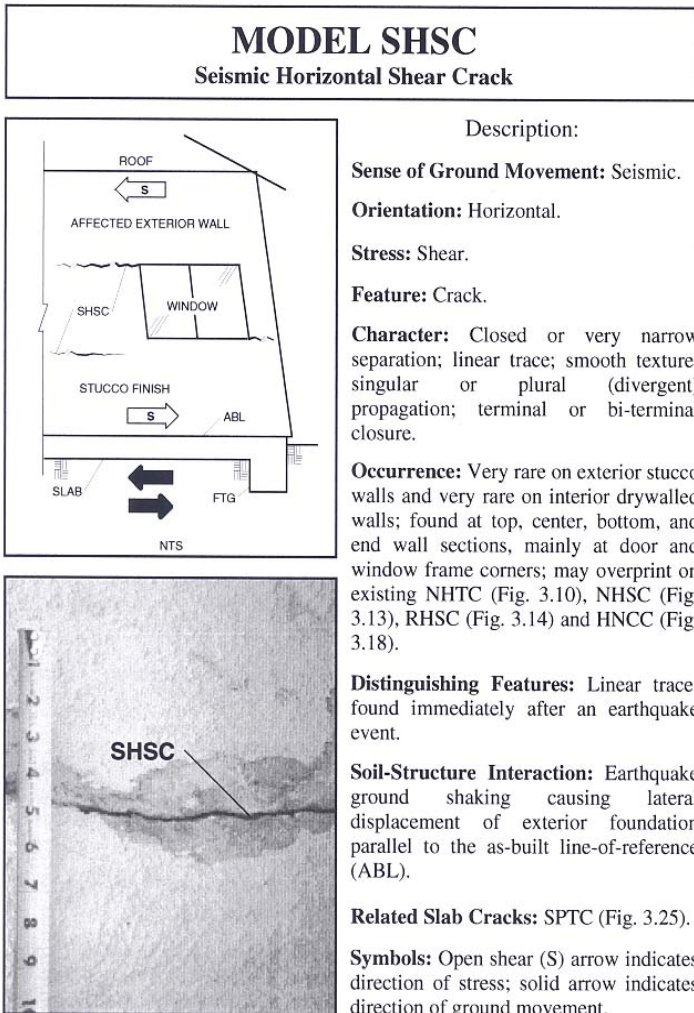
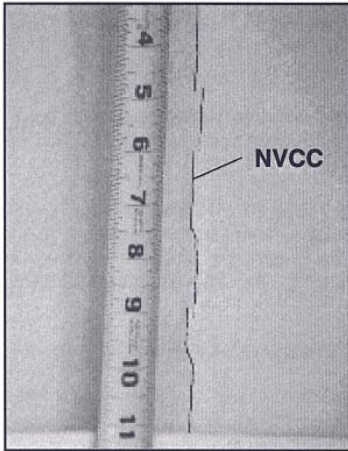
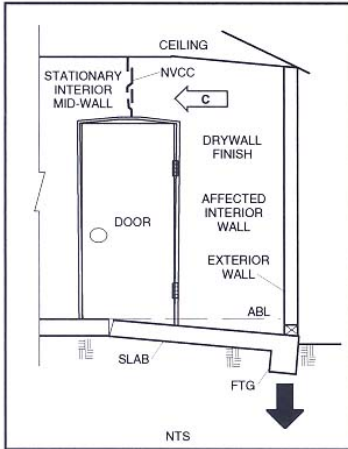


Figure 3.15 Sketch and photograph of a Seismic Horizontal Shear Crack (SHSC).

MODEL NVCC

Normal Vertical Compression Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Vertical.

Stress: Compression.

Feature: Crack.

Character: Closed separation; linear trace; buckle pattern; rough texture; singular or plural (divergent or convergent) propagation; total closure.

Occurrence: Very rare on exterior stucco walls and rare on interior drywalled walls; found at top and end wall sections, mainly at drywall construction joints above door or window frames; also at intersection of interior walls where joined to exterior walls; wall may exhibit bulging at crack location.

Distinguishing Features: Buckle pattern.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

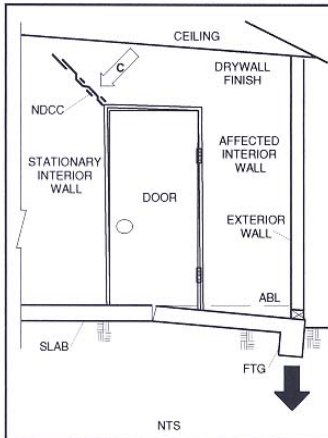
Related Slab Cracks: NOTC (Fig. 3.19) and NPTC (Fig. 3.22).

Symbols: Open compression (C) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

Figure 3.16 Sketch and photograph of a Normal Vertical Compression Crack (NVCC). Photograph highlighted for clarity.

CRACK PATTERNS IN BUILDINGS

MODEL NDCC Normal Diagonal Compression Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Diagonal.

Stress: Compression.

Feature: Crack.

Character: Closed separation; linear trace; buckle pattern; rough texture; singular or plural (divergent or convergent) propagation; total closure.

Occurrence: Very rare on exterior stucco walls and rare on interior drywalled walls; found at top and end wall sections, mainly at upper door and window frame corners; wall may exhibit bulging at crack location.

Distinguishing Features: Buckle pattern.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

Related Slab Cracks: NOTC (Fig. 3.19) and NPTC (Fig. 3.22).

Symbols: Open compression (C) arrow indicates direction of stress; solid arrow indicates direction of ground movement.

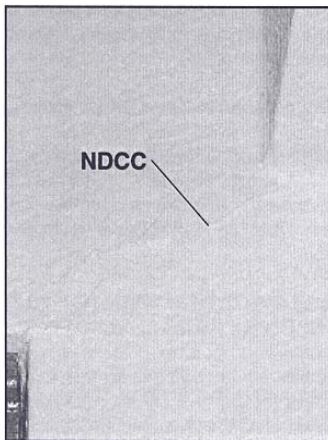


Figure 3.17 Sketch and photograph of a Normal Diagonal Compression Crack (NDCC).

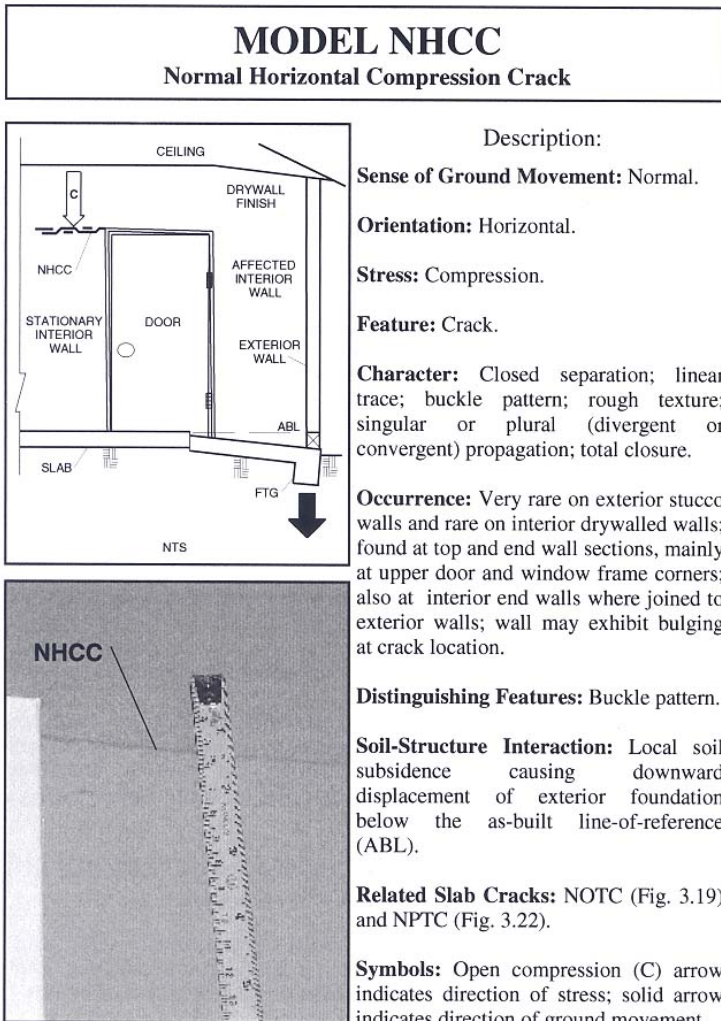
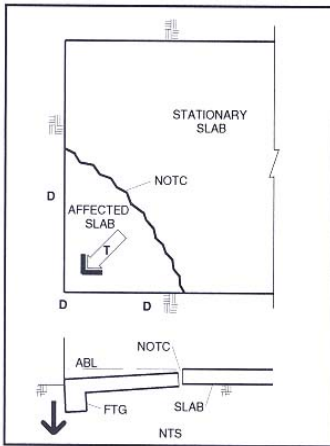


Figure 3.18 Sketch and photograph of a Normal Horizontal Compression Crack (NHCC).

CRACK PATTERNS IN BUILDINGS

MODEL NOTC Normal Oblique Tension Crack



Description:

Sense of Ground Movement: Normal.

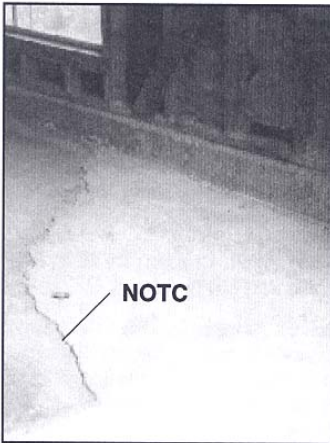
Orientation: Oblique.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or curvilinear trace; rough texture; singular or plural (divergent or convergent) propagation; terminal or parallel closure.

Occurrence: Common in slabs; found at corner slab sections; pitch of affected slab toward the exterior foundation.



Distinguishing Features: Oblique orientation; pitch of affected slab toward building exterior.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

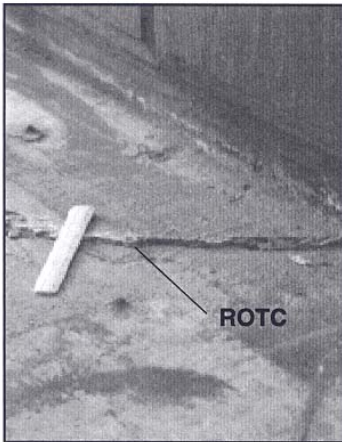
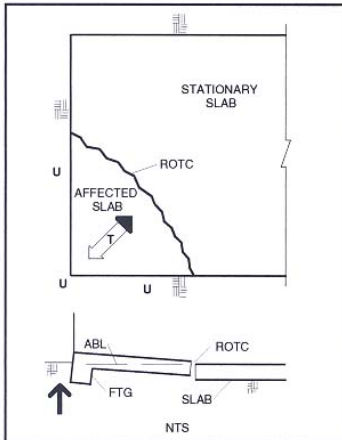
Related Wall Cracks: NVTC-1 (Fig. 3.1) and NDTC (Fig. 3.7).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of descending pitch; D indicates location of downward ground movement.

Figure 3.19 Sketch and photograph of a Normal Oblique Tension Crack (NOTC).

MODEL ROTC

Reverse Oblique Tension Crack



Description:

Sense of Ground Movement: Reverse.

Orientation: Oblique.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or curvilinear trace; rough texture; singular or plural (divergent or convergent) propagation; terminal or parallel closure.

Occurrence: Rare in slabs; found at corner slab sections; pitch of affected slab toward the interior foundation; occasional reverse-vertical displacement along crack where the affected slab may over-ride the stationary slab.

Distinguishing Features: Oblique orientation; pitch of affected slab toward building interior.

Soil-Structure Interaction: Local soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

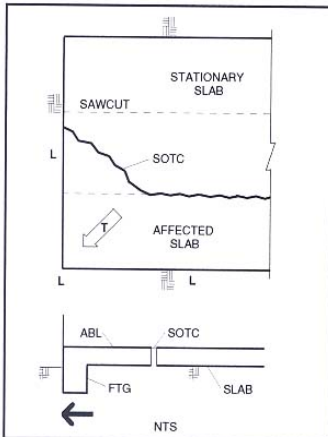
Related Wall Cracks: RVTC-1 (Fig. 3.3) and RDTC (Fig. 3.8).

Symbols: Open tension (T) arrow indicates direction of stress, solid arrow indicates direction of descending pitch; U indicates location of upward ground movement.

Figure 3.20 Sketch and photograph of a Reverse Oblique Tension Crack (ROTC).

MODEL SOTC

Seismic Oblique Tension Crack



Description:

Sense of Ground Movement: Seismic.

Orientation: Oblique.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or curvilinear trace; rough texture; singular or plural (divergent or convergent) propagation; terminal or parallel closure.

Occurrence: Very rare in slabs; found at side and corner slab sections; negligible pitch across affected slab; may overprint on existing NOTC (Fig. 3.19) and ROTC (Fig. 3.20) cracks.

Distinguishing Features: Oblique orientation and parallel separation along crack; found immediately after an earthquake event.

Soil-Structure Interaction: Earthquake ground shaking causing lateral displacement of exterior foundation parallel to the as-built line-of-reference (ABL).

Related Wall Cracks: SVTC (Fig. 3.6), SDTC (Fig. 3.9) and SHSC (Fig. 3.15).

Symbols: Open tension (T) arrow indicates direction of stress; L indicates location of lateral ground movement.

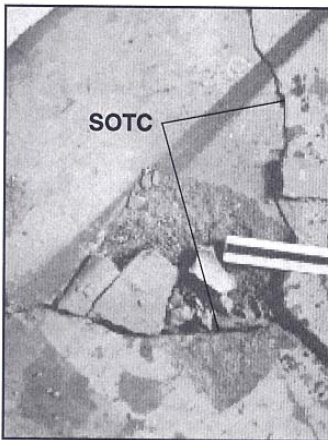
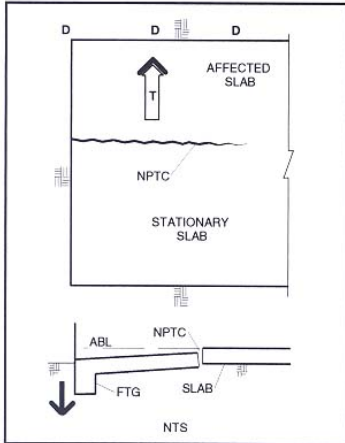


Figure 3.21 Sketch and photograph of a Seismic Oblique Tension Crack (SOTC).

MODEL NPTC

Normal Parallel Tension Crack



Description:

Sense of Ground Movement: Normal.

Orientation: Parallel.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or slightly linear trace; rough texture; singular propagation; terminal closure.

Occurrence: Very common in slabs; found at center and side slab sections; may occur along construction joints; pitch of affected slab toward the exterior foundation.

Distinguishing Features: Parallel orientation; pitch of affected slab toward building exterior.

Soil-Structure Interaction: General soil subsidence, or possibly rotational landslide, causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

Related Wall Cracks: NVTC-1 (Fig. 3.1) and NDTC (Fig. 3.7).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of descending pitch; D indicates location of downward ground movement.

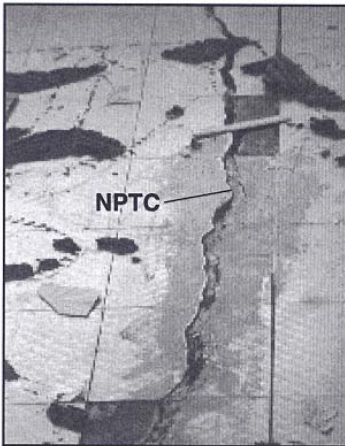
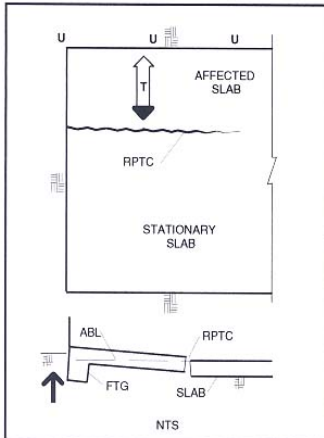


Figure 3.22 Sketch and photograph of a Normal Parallel Tension Crack (NPTC).

MODEL RPTC

Reverse Parallel Tension Crack



Description:

Sense of Ground Movement: Reverse.

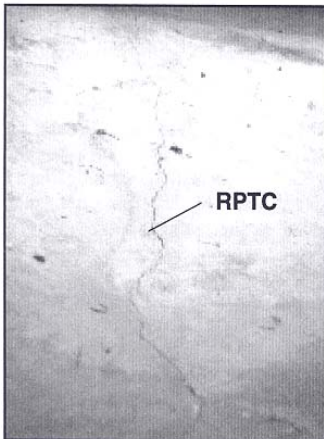
Orientation: Parallel.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or slightly linear trace; rough texture; singular propagation; terminal closure.

Occurrence: Common in slabs; found at side and center slab sections; pitch of affected slab toward the interior foundation.



Distinguishing Features: Parallel orientation; pitch of affected slab toward the interior foundation.

Soil-Structure Interaction: General soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

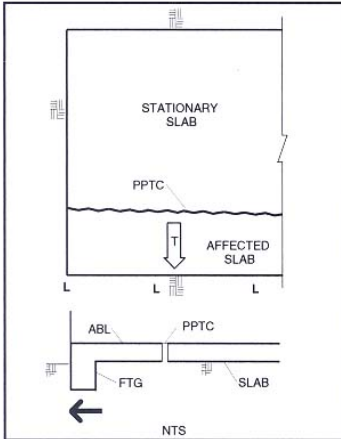
Related Wall Cracks: NVTC-1 (Fig. 3.1) and NDTC (Fig. 3.7).

Symbols: Open tension (T) arrow indicates direction of stress; solid arrow indicates direction of descending pitch; U indicates location of upward ground movement.

Figure 3.23 Sketch and photograph of a Reverse Parallel Tension Crack (RPTC).

MODEL PPTC

Pull-Apart Parallel Tension Crack



Description:

Sense of Ground Movement: Pull-apart.

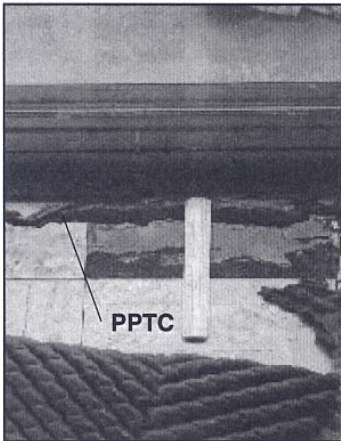
Orientation: Parallel.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or slightly linear trace; rough texture; singular or plural (divergent or convergent) propagation; terminal or parallel closure.

Occurrence: Common in slabs; found at center and side slab sections; may occur along construction joints; negligible pitch of affected slab.



Distinguishing Features: Parallel orientation; mainly horizontal displacement across crack.

Soil-Structure Interaction: General soil creep, slope creep, or possibly translational landslide, causing lateral displacement of exterior foundation parallel to the as-built line-of-reference (ABL).

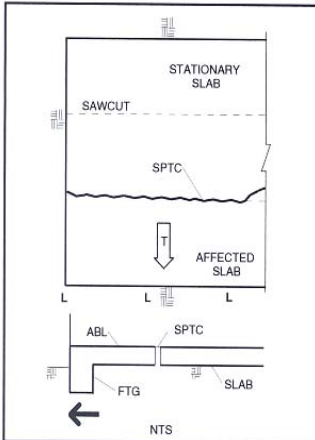
Related Wall Cracks: NVTC-1 (Fig. 3.1) and NDTTC (Fig. 3.7).

Symbols: Open tension (T) arrow indicates direction of stress; L indicates location of lateral ground movement.

Figure 3.24 Sketch and photograph of a Pull-Apart Parallel Tension Crack (PPTC).

MODEL SPTC

Seismic Parallel Tension Crack



Description:

Sense of Ground Movement: Seismic.

Orientation: Parallel.

Stress: Tension.

Feature: Crack.

Character: Open separation; linear or slightly linear trace; rough texture; singular or plural (divergent or convergent) propagation; terminal or parallel closure.

Occurrence: Rare in slabs; found at center and side slab sections; may occur along construction joints; negligible pitch of affected slab; may overprint on existing NPTC (Fig. 3.22), RPTC (Fig. 3.23) and PPTC (Fig. 3.24) cracks.

Distinguishing Features: Parallel orientation; mainly horizontal displacement across crack; found immediately after an earthquake.

Soil-Structure Interaction: Earthquake ground shaking causing lateral displacement of exterior foundation parallel to the as-built line-of-reference (ABL).

Related Wall Cracks: SVTC (Fig. 3.6), SDTC (Fig. 3.9) and SHSC (Fig. 3.15).

Symbols: Open tension (T) arrow indicates direction of stress; L indicates location of lateral ground movement.

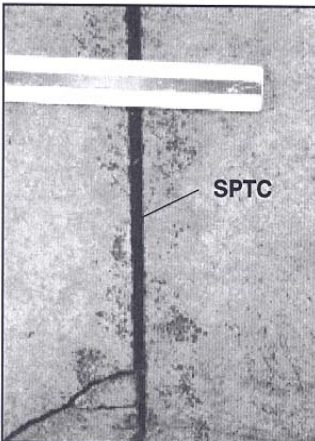
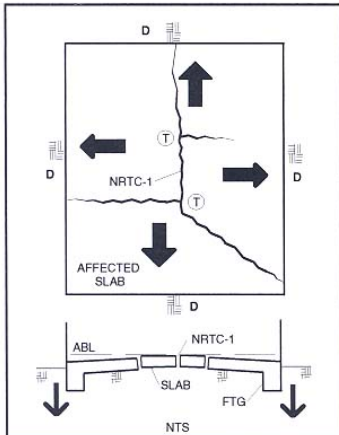


Figure 3.25 Sketch and photograph of a Seismic Parallel Tension Crack (SPTC).

MODEL NRTC-1

Normal Radial Tension Crack-Type 1



Description:

Sense of Ground Movement: Normal.

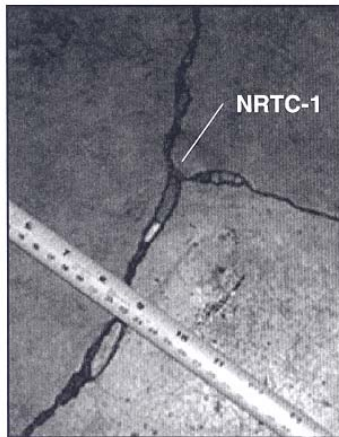
Orientation: Radial.

Stress: Tension.

Feature: Crack.

Character: Open separation; slightly linear or slightly curvilinear trace; radial triple junction pattern; rough texture; plural (divergent) propagation; terminal closure.

Occurrence: Common in slabs; found at center slab sections; pitch of affected slab toward exterior foundation.



Distinguishing Features: Radiating crack pattern; domed slab with pitch of affected slab toward building exterior.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of exterior foundation below the as-built line-of-reference (ABL).

Related Wall Cracks: NVTC-2 (Fig. 3.4) and NDTC (Fig. 3.8).

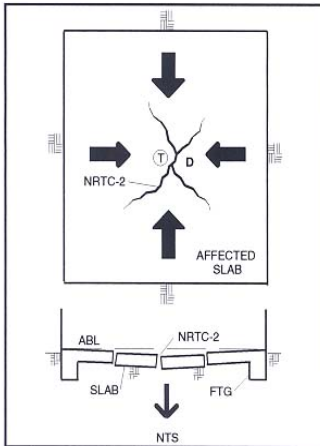
Symbols: Open tension (T) circle indicates area of applied stress; solid arrow indicates direction of descending pitch; D indicates location of downward ground movement.

Figure 3.26 Sketch and photograph of a Normal Radial Tension Crack-Type 1 (NRTC-1).

CRACK PATTERNS IN BUILDINGS

MODEL NRTC-2

Normal Radial Tension Crack-Type 2



Description:

Sense of Ground Movement: Normal.

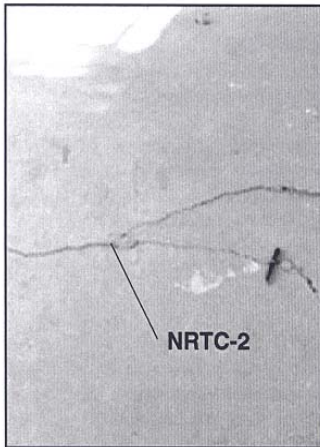
Orientation: Radial.

Stress: Tension.

Feature: Crack.

Character: Open separation; slightly linear or slightly curvilinear trace; radial triple junction pattern; rough texture; plural (divergent) propagation; terminal closure.

Occurrence: Common in slabs; found at center slab sections; pitch of affected slab toward interior foundation.



Distinguishing Features: Radiating crack pattern; dished slab with pitch of affected slab toward building interior.

Soil-Structure Interaction: Local soil subsidence causing downward displacement of center slab below the as-built line-of-reference (ABL).

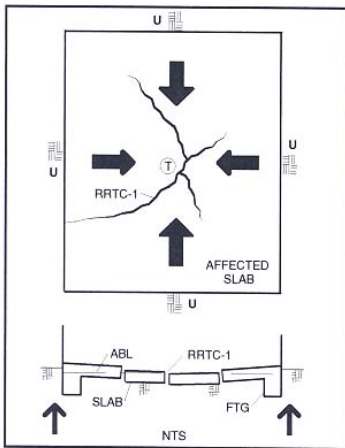
Related Wall Cracks: NVTC-2 (Fig. 3.2) and NDTC (Fig. 3.7).

Symbols: Open tension (T) circle indicates area of applied stress, solid arrow indicates direction of descending pitch; D indicates location of downward ground movement.

Figure 3.27 Sketch and photograph of a Normal Radial Tension Crack-Type 2 (NRTC-2).

MODEL RRTC-1

Reverse Radial Tension Crack-Type 1



Description:

Sense of Ground Movement: Reverse.

Orientation: Radial.

Stress: Tension.

Feature: Crack.

Character: Open separation; slightly curvilinear or curvilinear trace; radial triple junction pattern; rough texture; plural (divergent) propagation; terminal closure.

Occurrence: Common in slabs; found at center slab sections; pitch of affected slab toward the interior foundation.

Distinguishing Features: Radiating crack pattern; dished slab with pitch of affected slab toward building interior.

Soil-Structure Interaction: Local soil heave causing upward displacement of exterior foundation above the as-built line-of-reference (ABL).

Related Wall Cracks: RVTC-1 (Fig. 3.3) and RDTC (Fig. 3.8).

Symbols: Open tension (T) circle indicates area of applied stress, solid arrow indicates direction of descending pitch; U indicates location of upward ground movement.

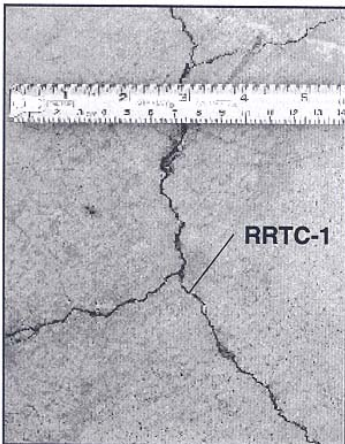
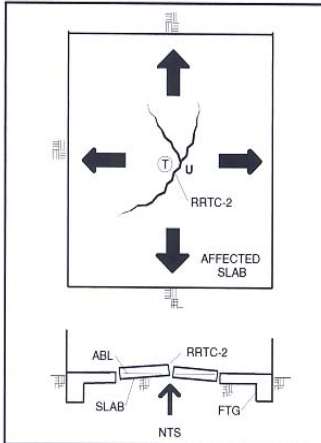


Figure 3.28 Sketch and photograph of a Reverse Radial Tension Crack-Type 1 (RRTC-1).

CRACK PATTERNS IN BUILDINGS

MODEL RRTC-2

Reverse Radial Tension Crack-Type 2



Description:

Sense of Ground Movement: Reverse.

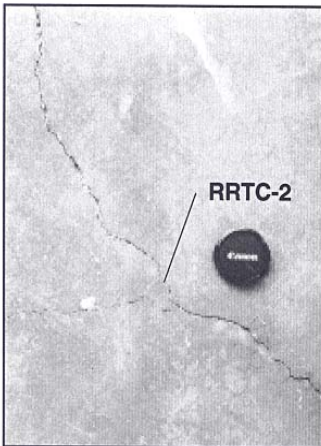
Orientation: Radial.

Stress: Tension.

Feature: Crack.

Character: Open separation; slightly curvilinear or curvilinear trace; radial triple junction pattern; rough texture; plural (divergent) propagation; terminal closure.

Occurrence: Common in slabs; found at center slab sections; pitch of affected slab toward exterior foundation.



Distinguishing Features: Radiating crack pattern; domed slab with pitch of affected slab toward building exterior.

Soil-Structure Interaction: Local soil heave causing upward displacement of center slab above the as-built line-of-reference (ABL).

Related Wall Cracks: RVTC-2 (Fig. 3.4) and RDTC (Fig. 3.8).

Symbols: Open tension (T) circle indicates area of applied stress; solid arrow indicates direction of descending pitch; U indicates location of upward ground movement.

Figure 3.29 Sketch and photograph of a Reverse Radial Tension Crack-Type 2 (RRTC-2).

Table 1. Index of crack models depicting the sense of ground movement and the type of cracks found in walls.

Sense of Ground Movement	Type of Crack									
	Tension					Shear				
	V	D	H	V	D	H	V	D	H	Compression
Normal	3.1	3.7	3.10	3.11	---	3.13	3.16	3.17	3.18	
	3.2	---	---	---	---	---	---	---	---	
Reverse	3.3	3.8	---	3.12	---	3.14	---	---	---	
	3.4	---	---	---	---	---	---	---	---	
Pull-Apart	3.5	---	---	---	---	---	---	---	---	
Seismic	3.6	3.9	---	---	---	3.15	---	---	---	

Explanation: V = Vertical, D = Diagonal, H = Horizontal; Figures 3.1 through 3.18 indicate referenced models.

CRACK PATTERNS IN BUILDINGS

Table 2. Index of crack models depicting the sense of ground movement and the type of cracks found in slabs.

Sense of Ground Movement	Type of Tension Crack		
	O	P	R
Normal	3.19	3.22	3.26 3.27
Reverse	3.20	3.23	3.28 3.29
Pull-Apart	-----	3.24	-----
Seismic	3.21	3.25	-----

Explanation: O=Oblique, P=Parallel, R=Radial; Figures 3.19 through 3.29 indicate referenced models.

It was necessary to highlight some photographs to make the crack pattern more visible, however, no attempt has been made to alter or exaggerate the crack during this highlighting process. Those photograph figures that have been highlighted are labelled.

PART 4-CRACK CHARACTER

Origin, Cause and Occurrence

Cracks originate as a form of stress relief (Nehdi, 1998) and represent distortion or strain of a building material. They occur in brittle (nonductile) materials such as plaster and concrete, and in ductile materials such as drywall, when the forces or stresses exceed the tensile, shear, or compressive strength of the material itself (Rose, 1989). Structural penetrations and construction joints including door and window frame corners in plaster walls, utility stem-ups through concrete slabs and drywall sheet abutments, function as focus points and lines for stress relief. Nehdi (1998)

asserts that cracks alone are seldom a threat to the building's safety for occupancy or to its structural integrity.

There are two causes which produce cracks in building materials: one is the internal stress developed within a material itself and the other is the external stress transferred to a material from an outside force (Rose, 1989). Internal stresses to plaster or concrete include material shrinkage (the loss of water, inappropriate aggregate, or chemistry). External stresses transferred to materials are derived from either geologic- or structure-induced forces. Geologic-induced processes that initiate ground movements are primarily soil subsidence, soil expansion, landslides, fill-wedge creep, slope creep, soil creep, and earthquakes. Structure-induced processes include thermal shock, moisture or temperature-induced expansion and contraction, sonic vibrations, concrete creep and sag, wind loads, live loading of floors, mechanical vibrations, tree root uplift, and vehicle loads, just to name a few (Nehdi, 1998).

Lineaments, Growth, and Trace

Crack lineaments will grow and behave differently in brittle and ductile materials and create a variety of patterns. They are known to grow, mature and may become more complex in development with the continuance or increase of stresses. Should the stress decrease or cease entirely, the crack lineaments will arrest in growth. The developed crack lineaments will form common patterns that are easily recognized and classified.

Incipient cracks may grow as a singular, unidirectional terminated lineament emanating from a point or line of origin within an envelope of stress. They may also grow as a plural, bidirectional doubly-terminated lineament emanating from a point of origin within an envelope of stress.

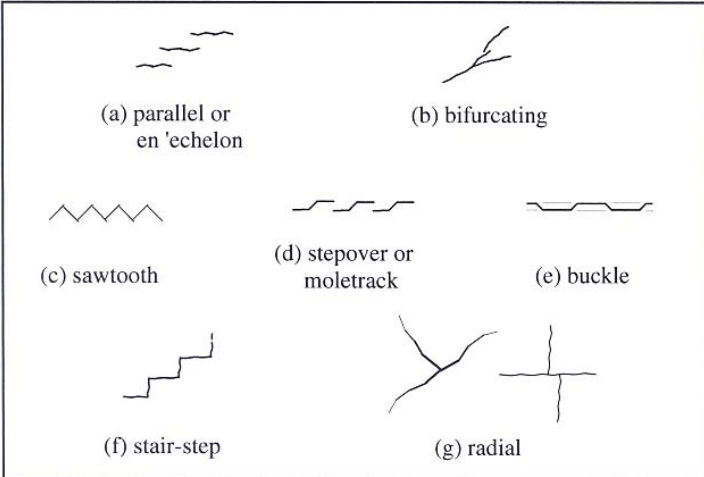
CRACK PATTERNS IN BUILDINGS

Divergent growth occurs in tensional stress environments in which an open crack will propagate outward perpendicular to the axis of maximum extension. Convergent growth occurs in compressional stress environments in which a closed (crushed) crack will propagate outward perpendicular to the axis of maximum compression. As stress increases, the crack propagation may change directions or another crack may occur from the same point of origin. Crack capture, or the merging of two cracks to become one, may occur from two nearby points of origin where the envelopes of stress overlap. A plural lineament often develops a double or triple-junction appearance where at least two crack lineaments simultaneously grow and propagate outward from a common focus point. Crack propagation and growth will always reflect the type of stress applied to a particular building material.

Cracks will typically display a linear or curvilinear trace. However, in many instances they will display an irregular trace. Certain irregular traces appear to be unique to either plaster walls, drywalled walls, and slabs. For instance, in plaster walls they can be parallel or *en'echelon*, bifurcating, or sawtooth. In drywall, they can be stepover, buckle and stairstep; in slabs, they can be radial. All traces can be reduced to their origin which will identify the fundamental singular or plural type of crack pattern. Some traces are diagnostic to particular types of ground movement conditions, Table 3.

A developing crack will display a single pattern with displacement most affiliated with the causative geologic hazard. The factors dictating displacement across the crack are the type of geologic condition and the location of the applied stress affecting the building foundation. As the crack matures, dominant and subordinate displacement may be

Table 3: Types of irregular crack traces commonly found in walls (plaster and drywall types) and slabs.



Traces (a), (b) and (c) are found in plaster walls. Traces (d), (e) and (f) are found in drywalled walls. Trace (g) is found in slabs.

noted. Dominate displacements may single out the geologic cause, but combined subordinate displacement could identify more than one geologic hazard occurring simultaneously. For example, a NPTC with subordinate horizontal displacement may suggest simultaneous ground subsidence and soil creep condition.

Perhaps the most difficult geologic condition to discern by crack pattern recognition alone is landslide ground movement. Landslides will always generate dip-slip crack separations with combined horizontal and downward vertical

CRACK PATTERNS IN BUILDINGS

displacement. Depending upon the type of landslide (whether rotational or translational) (Transportation Research Board, 1980), and where the headscarp is located below the house foundation, one direction of displacement may be dominant. Rotational-type landslides, with a steeply dipping headscarp and circular slip surface, may generate normal vertical shear cracks (NVSC) in walls and normal parallel tension cracks (NPTC) in slabs with dominate vertical displacement. Translational-type landslides, with shallow dipping planar surfaces, may generate pull-apart vertical tension cracks (PVTC) in walls and pull-apart parallel tension cracks (PPTC) in slabs with dominate horizontal displacement. Supporting evidence from other indicators, either geological or structural, must also be analyzed before concluding the cause of building distress as landslide related.

Description

The description for cracks pertains to their lineament pattern found in plaster walls, drywalled walls, and concrete slabs. For proper classification, crack character and crack occurrence should be accurately described by the practitioner. Other important descriptive information should include distinguishing any special features of the crack, Figure 4.

The character of cracking is described by separation, texture, closure, trace, and weathering. Crack separations are described as closed, very narrow, narrow, wide, and very wide. The surface texture of the crack ranges from very smooth, to smooth, to rough, to very rough. Closure describes the type of end point termination for cracks in walls and slabs. Terminated and doubly-terminated closure has one or two end points, respectively. Parallel closure has no end points. Total closure applies to closed cracks. Trace describes the linearity of the crack which includes linear, curvilinear,

CRACK DESCRIPTION

SEPARATION

CLASSIFICATION	SEPARATION inches (mm)	
	WALLS	SLABS
CLOSED	0	0
VERY NARROW	1/32 (0.8)	1/16 (1.6)
NARROW	1/16 (1.6)	1/8 (3.2)
WIDE	3/32 (2.4)	3/16 (4.8)
VERY WIDE	> 1/8 (3.2)	> 1/4 (6.4)

PROBABILITY

CLASSIFICATION	DESCRIPTION
COMMON	Frequent crack pattern appearance relative to a particular ground movement condition.
RARE	Seldom crack pattern appearance relative to a particular ground movement condition.

SURFACE TEXTURE

CLASSIFICATION	DESCRIPTION
VERY SMOOTH	Visually smooth and is smooth to the touch, no granular texture.
SMOOTH	Granular texture on the crack surface is visible and distinctly felt.
ROUGH	Granular texture of the crack surface is visible and feels abrasive.
VERY ROUGH	Large angular grains, vertical steps and angular ridges on crack surface.

PROPAGATION AND GROWTH

CLASSIFICATION	DESCRIPTION
SINGULAR	Unidirectional propagation from a point or line of origin.

TRACE

CLASSIFICATION	DESCRIPTION
LINEAR	Straight trace with total absence of any curves.
SLIGHTLY LINEAR	Near straight trace with slight curvature at mid section of crack.
SLIGHTLY CURVILINEAR	Mostly curved trace with slight curvature at end-section of crack.
CURVILINEAR	Totally curved trace with total absence of any linear sections.
IRREGULAR	Sawtooth, radial, stepover, stair-step, orthogonal, bifurcating, buckle, and <i>en échelon</i> .

CRACK PATTERNS IN BUILDINGS

CLOSURE		PLURAL	Bi-directional propagation from a point origin.
CLASSIFICATION	DESCRIPTION		
TERMINATED	Separation closes unidirectionally toward a single end-point.		
DOUBLE-TERMINATED	Separation closes bi-directionally toward two end-points.		
PARALLEL	Separation without closure.		
TOTAL	No separation.		

EXTENT OF CRACKING		CLASSIFICATION	WEATHERING DESCRIPTION
CLASSIFICATION	DESCRIPTION		
WIDESPREAD	Greater than 25 LF of cracking per 100 SF of wall/slab surface area.	UNWEATHERED	Sharp and angular exterior edges and angularities on surface, no discoloration, original texture preserved, clean with no filling materials or minerals.
SOME	Between 15 LF and 25 LF of cracking per 100 SF of wall/slab surface area.	SLIGHTLY	Slightly rounded exterior edges and angularities on surface, slight discoloration, original texture preserved, slight filling with foreign materials or minerals.
FEW	Between 10 LF and 15 LF of cracking per 100 SF of wall/slab surface area.	MEDIUM	Some rounded exterior edges and angularities on surface, some discoloration, texture mainly preserved, moderate filling with foreign materials or minerals.
OCCASIONAL	Less than 10 LF of cracking per 100 SF of wall/slab surface area.	HIGHLY	Totally rounded exterior edges and angularities on surface, total discoloration, texture partially preserved, totally filled with foreign materials or minerals.

Figure 4. A chart for describing the character of cracking in walls and slabs.

and irregular. An irregular trace may reflect mature crack configurations. Crack surfaces are exposed to chemical (decomposition) and mechanical (disintegration) weathering. Weathering is based upon the preservation of interior angularities and exterior edges, color, texture, and the foreign materials, or minerals with which they are filled.

The occurrence of cracks is described by extent, probability, and location. Extent describes cracks as widespread, some, few, and occasional which is categorized by the cumulative crack length within a specific surface area. Probability describes how common (frequent) or rare (seldom) the cracks appear for the type of geologic condition affecting a particular part of the building. Location describes where cracks are situated on a defined surface. For walls, this includes descriptions such as top, bottom, end and corner sections. For slabs, this includes descriptions such as corner, side, and center.

Shear cracks display minute deviations in crack trace which are unusual and distinctive, however, significant information may be derived from detailed observations. For instance, a normal horizontal shear crack (NHSC) in drywall resulting from floor deflection will generate an irregular stepover or moletrack trace along the primary crack which distinguishes the direction of wall displacement, Figure 5. These irregular traces are unique to shear cracks that occur in drywall.

In most instances, slab cracks will correlate with wall cracks given a particular mode of building movement and together will provide collaborating data in depicting the responsible geologic hazard and affect on the building.

Finally, the degree of confidence and certainty in interpreting soil-structure interactions is directly dependent upon the accuracy of the crack description.

CRACK PATTERNS IN BUILDINGS

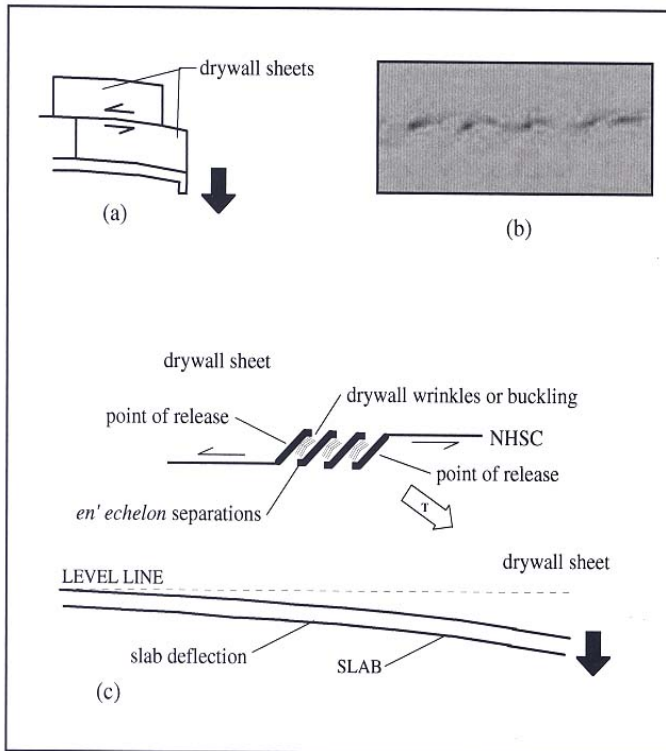


Figure 5. Relationship of floor deflection and the normal horizontal shear crack (NHSC) in interior drywall walls. Diagram (a) shows left-lateral slip (i.e., shear) along construction joint at adjoining drywall sheets as foundation deflects downward, (b) shows photograph of NHSC of similar slip in drywall sheet, and (c) shows the mechanics of wall slip along the NHSC. In many instances, as shown in (c), *en'echelon* separations stemming from the NHSC points of release form irregular stepover or moletract traces along the shear crack. Solid arrow indicates direction of foundation displacement. Tension arrow (T) denotes the axis of wall elongation.

Activity

Crack activity is a reflection of building behavior. It defines the level of ground movement relative to building distortion in real-time. The rate of cracking can provide the ability to forecast future building distress (Audell, 1999).

Geologic processes generates two types of cracks found in buildings: live cracks and static cracks. Live cracks are created by, or in response to, continuous or recurrent building stresses caused by dynamic (i.e., active) geologic processes such as the constant upward or downward vertical movement of soil sustained by the swell and shrink capability of expansive clay. These cracks increase in size or recur after repair. Static cracks are created by, or in response to, a single incident or transient geologic processes such as a seismic event. Once formed, static cracks maintain a constant size and when repaired do not reopen. The crack induction potential is relieved once the stress has expended its energy in the fracture (Rose, 1989, and Means, 1998).

Ground movement can be qualitatively measured based upon crack occurrence relative to the age of the material in which the crack occurs, Figure 6. It is best determined by observing cracks in plaster or drywalled walls that receive periodic repair. Four levels of ground movement are defined: low, moderate, high, and unallowable. The first occurrence or recurrence of cracking through one year old patch or paint generally denotes a high level of ground movement. The recurrence of cracking through patch or paint ranging from 2 to 7 years in age provides the greatest certainty for ground movement assessment. Establishing an accurate age of the crack filler is essential. Forecasting building movement may be approximate at best. However, it is reasonable to state that a building currently undergoing movement will continue to undergo movement should the causative geologic hazard

CRACK PATTERNS IN BUILDINGS

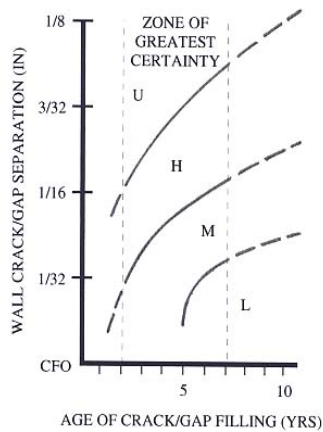


Figure 6. Determination of the level of ground movement. Abbreviations: CFO-crack first occurrence, U-unallowable, H-high, M-moderate, L-low.

be allowed to persist.

Overprinting

Crack overprinting is the development of renewed crack displacement initiated by a new geologic cause different from the one which created the original crack. For instance, a normal parallel tension crack (NPTC) initially caused by ground subsidence may become overprinted by a pull-apart parallel tension crack (PPTC) caused by slope creep. Overprinting also occurs when ground movement causes an existing shrinkage crack in a slab to become displaced creating a new type of crack. Likewise, earthquake ground shaking can overprint a seismic signature on a crack previously developed by other kinds of ground movements.

Identification of live crack overprinting involves proper

crack classification, recognition of distinguishing crack features, and knowledge of crack patterns caused by variable types of ground movements. A known history of building movement also identifies those cracks that have been overprinted. A misdiagnosis of overprinted cracks may suggest an inaccurate geologic cause for current building movement.

Where ground movements or seismic shaking cause crack overprinting, the previous crack name is to be superseded by the new crack name. Recording the original crack name and the overprinted crack name can provide a complete history of building performance.

Complexity

The complexity of cracking depicts the non-uniform change in dynamic soil-structure interaction. It is dependent upon the following factors: the sense and location of ground movement, the type and location of applied stress, and response of the building material being distorted. The complexity, as related to crack pattern expression, is considered "simple," "compound," and complex." It can also refer to either local or widespread areas of distortion. Complexity is more distinguishable in wall cracks than in slab cracks.

Simple cracks reflect minimal non-uniform and localized soil-structure interaction. Their pattern indicates a single sense of ground movement and applied stress. The majority of cracks in buildings fall into this category. These cracks represent the predictable early stages of low level ground movements and distortion of the building material. They are expressed as a single lineament feature. A simple, normal vertical tension crack-type 2 (NVTC-2) is shown in Figure 7.

Compound cracks reflect increasing non-uniform

CRACK PATTERNS IN BUILDINGS

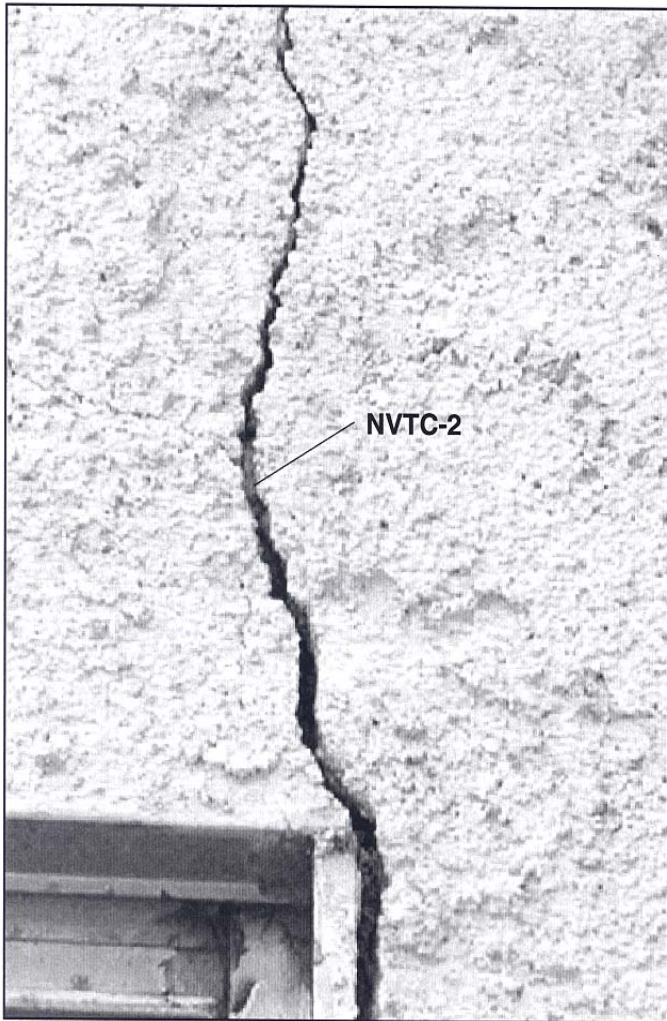


Figure 7. Simple (complexity) cracking. A normal vertical tension crack-type 2 (NVTC-2) occurring at a window frame corner.

soil-structure interaction. They are a single lineament that has changed in pattern during development because of a change in the sense of ground movement, and/or type of applied stress. These cracks are common in buildings where the geologic setting possesses more than a single hazard. They also represent an intermediate level of ground movement and distortion to the building material. Such is the case in Figure 8 where a developing normal vertical shear crack (NVSC) becomes a normal horizontal tension crack (NHTC).

Complex cracks reflect a chaotic soil-structure interaction. They are expressed as the simultaneous generation of various crack patterns because of the influence of two or more senses of ground movement and a change in location or types of applied stress. Unusual architectural building configurations also contribute to the non-uniform distribution and release of stress. Coupled geologic hazards causing stress at a focus point usually develops more than one crack pattern, although this situation is rare. Also, extreme building distortion generates irregular patterns. In some cases, sympathetic compression cracks, caused by crushing, may be formed at the post and beam connection in walls during periods of severe ground movement. These cracks represent a more advanced, or mature state of ground movement and a high level of distortion to the building material. This is demonstrated in Figure 9 where a normal horizontal shear crack (NHSC) coexists with a normal diagonal tension crack (NDTC).

Gaps and Separations

Building elements may be predisposed to displacement along construction joints or cold contacts in a wall or floor slab. These would include drywall sheet abutments, and

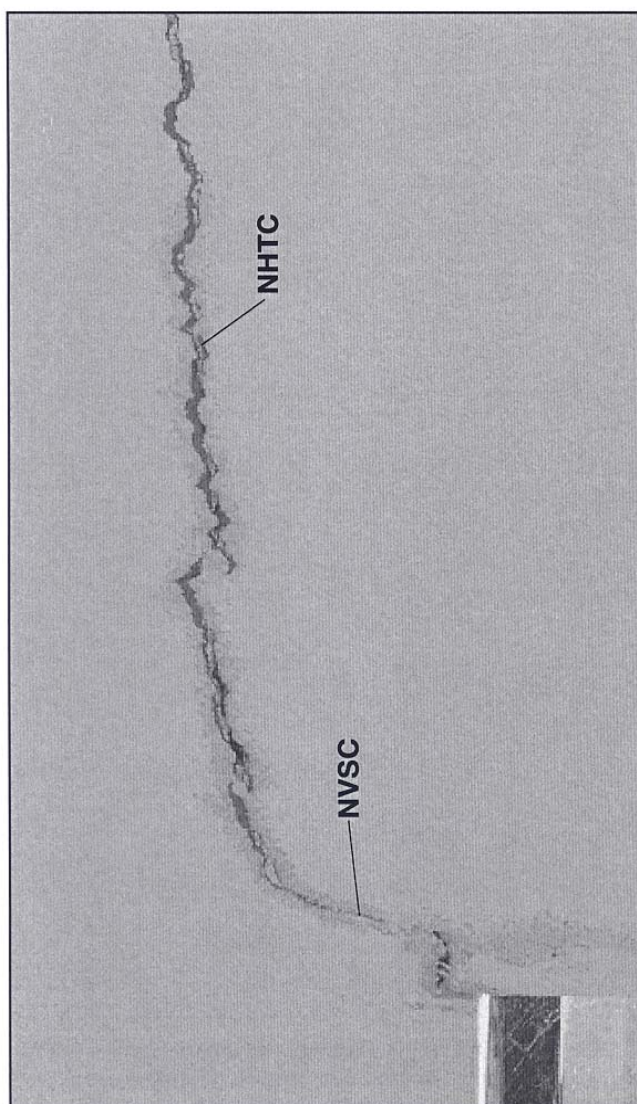


Figure 8. Compound (complexity) cracking. A normal vertical shear crack (NVSC) becomes a normal horizontal tensional crack (NHTC) occurring at a window frame corner.

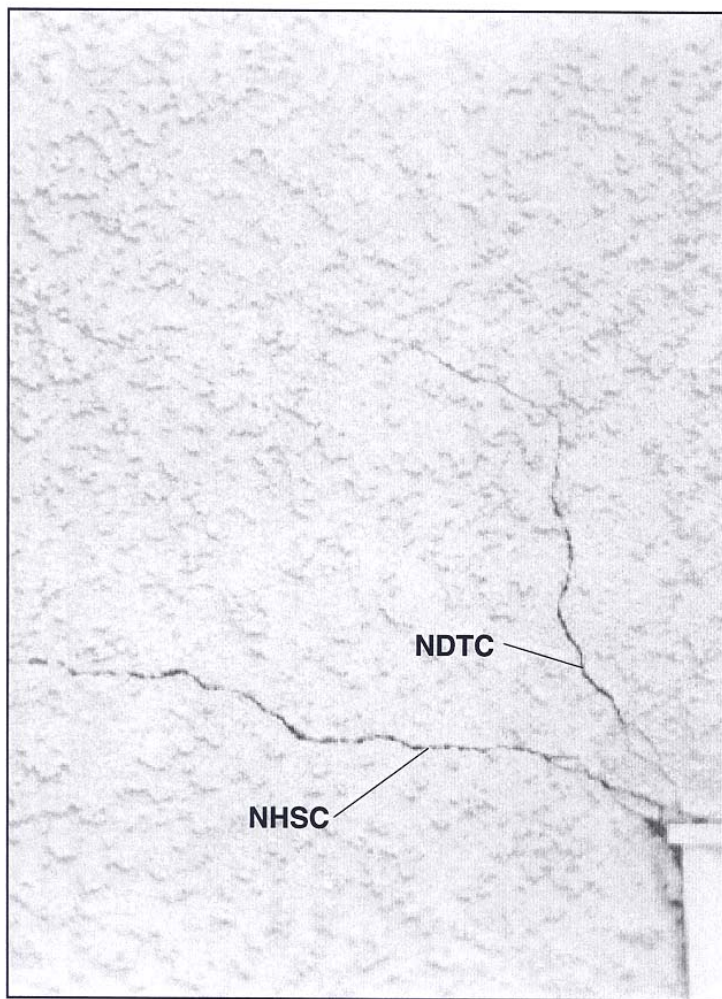


Figure 9. Complex (complexity) cracking. A normal diagonal tension crack (NDTC) and normal horizontal shear crack (NHSC) occurring at a window frame corner.

CRACK PATTERNS IN BUILDINGS

expansion joints in slabs, for example. Gaps, not cracks, are formed at these locations once displacement has occurred. They are included in the nomenclature scheme. For instance, a gap at the floor slab and footing is named a "pull-apart parallel tension gap" (PPTG), Figure 10.

Separation refers to the space in cracks and gaps. The separation will be parallel or angular (vee-ed, "V") depending upon the uniformity of ground movement and resulting building behavior. Separation will usually indicate the particular direction and propagation of stress release through a building material, displacement of one building element relative to another, the extent of building displacement, and if building elements are square or plumb.

Cracks Not Identified

There are probably some wall and slab crack patterns not identified here; however, newly discovered cracks can readily be assigned to the CCS. Additional studies may lead to a complete identification of all types of ground movement related cracks that occur in buildings.

PART 5-APPLICATION AND RELATIONSHIPS

The CCS is one of many tools available to the practitioner for evaluating building performance. To properly use the CCS, certain geologic and construction aspects must be known about the property and building, respectively. Otherwise, a misdiagnosis of a crack pattern may lead to an inaccurate soil-structure interaction analysis.

Initially, the practitioner must determine some basic information about the property's geologic character, its graded configuration, and the type of building constructed. Geologic information includes the identification of the following characteristics: geomorphology (i.e., landforms),

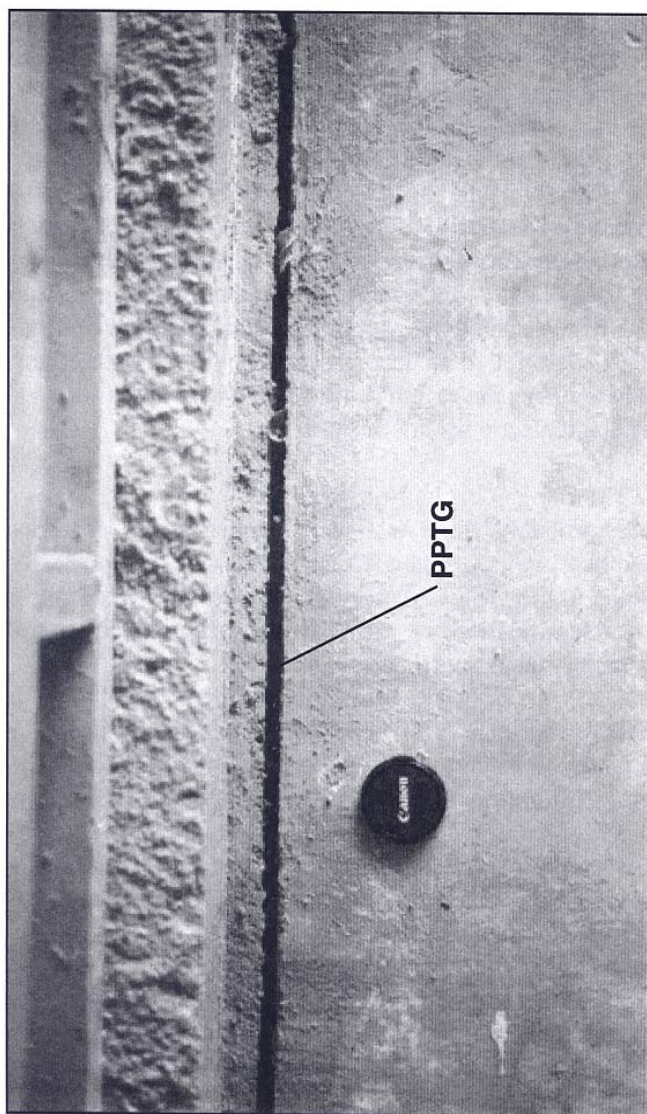


Figure 10. Gap at floor slab and footing. Note near perfect parallel tension gap (PPTG).

CRACK PATTERNS IN BUILDINGS

surface rock and soil types and their engineering properties, subsurface soil stratigraphy, bedrock structure, groundwater regimes, and the regional seismic element. The graded configuration (i.e., level or hillside pad and cut-lot or fill-lot) must be known. The type of building (i.e., foundation and super-structure) and the type of materials used in construction also needs to be identified. Obtaining and verifying this information is a prerequisite to using and applying the CCS.

The site inspection requires the performance of several important tasks in order to record the three-dimensional aspect of building distortion as related to foundation displacement. The practitioner needs to identify foundation upward heave, downward settlement, and lateral pull-apart. One important task is a crack survey which identifies all three types of displacement. Another is the floor level survey, which only identifies the heave or settlement mode of displacement. Other lesser important tasks include the identification of door and window frames that may be out-of-square, bowed walls, and doors that swing or jam within their frames. All of these tasks complement each other, provide supporting evidence, and help to identify building behavior.

The CCS complements the crack survey because it is an orderly method (code) of describing and characterizing cracks. It does not necessarily dictate the order in which the elements of the system are identified. As long as the practitioner properly assembles the key elements of the code, the description is complete. First, identify the feature as a crack or gap. Second, identify the orientation of the feature. Third, identify the type of stress creating the feature. Fourth, identify the sense of ground movement. Lastly, use the appropriate crack model for comparison and final determination of the crack name.

When performing a crack survey, it is necessary to evaluate all cracks and gaps throughout the entire building. Identification of a single pattern may suggest a geologic cause for ground movement, but supporting evidence from other local patterns may identify the actual cause. Ground movement can cause a single or uniform type of stress in building materials. However, it can also initiate multiple stresses creating a number of different crack and gap patterns that may develop simultaneously.

The floor level survey serves to identify the upward or downward vertical deflection of a building's foundation. It does not identify lateral foundation displacement. Floor deflection has two primary and distinct components; differential displacement and angular distortion. Differential displacement pertains to the maximum vertical difference in uneven floor elevations, relative to heave or settlement, from a defined point of reference. Angular distortion pertains to the slope of a floor. It is measured as the vertical differential in elevation relative to a defined horizontal distance (i.e., rise-over-run). Initially, a floor's as-built plane-of-reference must be known or assumed to determine deflection. The practitioner must distinguish whether a floor has deflected because of ground movement or reflects defective construction (e.g., the floor was built out-of-level). The best method for this determination is to check for cracks in slabs or foundation footings. Ordinarily, cracked slabs and footings denote a ground movement condition. Manometers or auto-leveling lasers are precision instruments best suited for measuring floor deflection.

For lateral foundation displacement the practitioner must rely on wall, slab, and foundation crack and gap separations for this determination (Boone, 2001). Lateral displacement is exemplified by the lack of a vertical elevation differential

CRACK PATTERNS IN BUILDINGS

across an affected floor. Telltale slab and wall crack patterns depicting lateral foundation displacement are the pull-apart parallel tension crack (PPTC) and the pull-apart vertical tension crack (PVTC), respectively.

Cracks found in areas of the building, other than walls and slabs, can also be classified by the CCS. This would include cracks found in ceilings and in foundation footings. The appropriate orientation of the surface in which the crack occurs dictates the pattern to be assigned. For level ceilings the patterns for slab cracking is used, however, for inclined ceilings the practitioner must determine the best-fit pattern. For footings, the crack pattern chosen is dependent upon the footing's configuration taken in a transverse sectional view. Should the footing configuration be square or rectangular with the long axis oriented in the vertical plane, then the nomenclature for wall cracks is used. If the footing configuration is rectangular with the long axis oriented in the horizontal plane, then the nomenclature for slab cracks is used.

To create a CCS crack survey map, start by plotting the trace of all cracks in walls, slabs, and footings in elevation and floor plan views. Match the appropriate crack pattern model to the crack pattern indicated on the map. From the crack pattern model, draw the vector of greatest stress for walls and slabs, the direction of foundation displacement, the as-built line-of-reference for slabs, and the direction of ground movement. Label all crack patterns in accordance to the CCS. Further, note all supporting evidence of building movement as indicated above. After all the information is compiled, the crack map is complete and ready for a soil-structure interaction analysis.

An example is shown on a crack map (Figure 11) of how the CCS can facilitate the description, identification, and

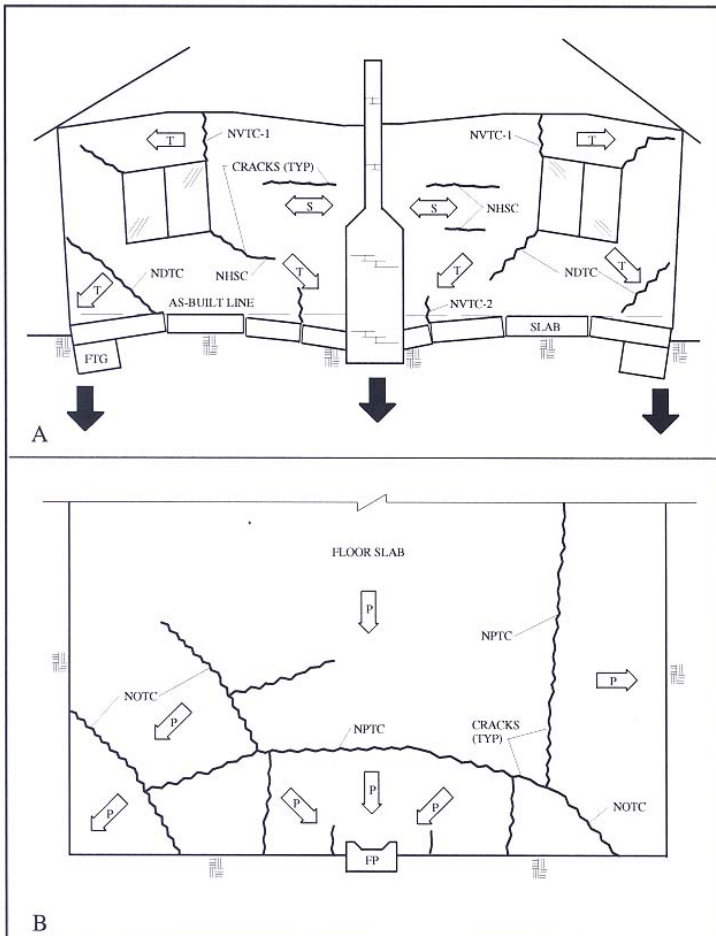


Figure 11. Crack map. A) Wall view and B) slab view show various simple and compound crack patterns caused by ground subsidence. Open arrows in Diagram A indicate direction of tension (T) and shear (S) stress. Solid arrows indicate direction of ground movement. Open arrows in Diagram B indicate direction of downward floor deflection or pitch (P).

CRACK PATTERNS IN BUILDINGS

analysis in relation to ground movements. This crack map illustrates how a structure situated on a compressible soil settled differentially creating predictable floor pitch and crack patterns in walls and slabs.

Anomalies can develop in a soil-structure analysis. Troubleshooting the analysis will generally work out the discontinuities and lead to an error free interpretation. The more common errors usually pertain to procedural issues, such as: neglecting to examine the entire property and building; incorrect classification of the crack pattern; incorrectly identifying the geologic processes of the property and those problematic hazards that affect the building; omitting a floor level survey; or inaccurate correlation of crack patterns with the floor level survey data.

Obtaining a history of the property and building from the owner can provide important information for the soil-structure interaction analysis. It can also create discrepancies in what is observed by the practitioner and the testimony of the owner. For instance, an owner may claim that a past earthquake created a particular wall crack; however, upon closer examination the crack pattern and floor deflection measurements clearly identifies foundation heave from an expansive soil condition as the cause. Differentiating seismic and aseismic induced ground movements can be challenging, although is considered essential when evaluating crack patterns.

The practitioner must exercise diligence and caution in evaluating building cracks. Should there be any difficulty in properly diagnosing cracks then the practitioner must recognize the need for a professional geologic opinion. After all, the information provided herein is for use by the professional practitioner, but is ultimately intended for the public's benefit. A thorough and comprehensive site

evaluation, utilizing the described methods discussed above, should easily delineate the "geologic cause and structural effect" of building behavior.

PART 6-SUMMARY

By using this field guide geologists, engineers, architects, building inspectors and contractors, can distinguish building cracks initiated by ground movement related causes. The simplicity of the field guide can be understood by both the scientist and layman. It is recommended for use as a professional tool for the inspection of buildings where ground movement is a concern. Practical applications would include pre-blast building surveys for mining, post-earthquake building damage surveys for insurance claims, residential geologic evaluations for ownership transfer, baseline crack maps for forensic building surveys, geologic hazard-impact-risk studies for litigation support, and evaluating construction defect. A higher degree of certainty is obtained when using the CCS for the qualitative assessment of ground movement-induced building cracks. This field guide also provides a rationale for conveying scientific information to the general public.

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CRACK PATTERNS IN BUILDINGS

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CRACK PATTERNS IN BUILDINGS

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HARRY S. AUDELL

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CRACK PATTERNS IN BUILDINGS

INDEX

A

Activity, 48

Angular distortion, 58

B

Bi-directional, 40, 45

Bifurcating pattern, 41, 44

Buckle pattern, 41

C

Capture, 41

Cause, 39

Character, 39

Classification, 3, 4

Closure, 43, 45, 46

Complexity, 50

 Simple, 50

 Compound, 50

 Complex, 52

Convergent growth, 41

Curvilinear trace, 41, 42, 44, 46

D

Deflection, of floor, 42, 46, 47, 58

Description, 43, 44

Differential displacement, 41, 43, 58

Distortion, 39, 48, 50, 51, 52

Divergent growth, 40

Dominate displacement, 41, 42, 43

Doubly-terminated closure, 40, 43, 45

E

En 'echelon pattern, 41, 42, 44, 47
Expansion, 6
Expansive clay, 48
External stress, 40

F

Feature, type of, 8
Footing crack orientation, 59

G

Gap, 52
Geologic hazard, 2, 3
Ground movement, 1, 41, 48, 49
 sense of, 6
 Normal, 6
 Reverse, 6
 Pull-apart, 6
 Seismic, 6
Ground shaking, 6
Growth, 40

H

Horizontal plane, 7

I

Internal stress, 40
Irregular trace, 41, 42, 46

L

Landslides, 6
Lineament, 40, 41, 42, 43

CRACK PATTERNS IN BUILDINGS

Linear trace, 41, 44, 46

Location, 46

M

Models, 8

in slabs:

- Normal oblique tension crack, 27
- Normal parallel tension crack, 30
- Normal radial tension crack-1, 34
- Normal radial tension crack-2, 35
- Pull-apart parallel tension crack, 32
- Reverse oblique tension crack, 28
- Reverse parallel tension crack, 31
- Reverse radial tension crack-1, 36
- Reverse radial tension crack-2, 37
- Seismic oblique tension crack, 29
- Seismic parallel tension crack, 33

in walls:

- Normal diagonal compression crack, 25
- Normal diagonal tension crack, 15
- Normal horizontal compression crack, 26
- Normal horizontal shear crack, 21, 46, 47
- Normal horizontal tension crack, 18
- Normal vertical compression crack, 24
- Normal vertical shear crack, 19
- Normal vertical tension crack-1, 9
- Normal vertical tension crack-2, 10
- Pull-apart vertical tension crack, 13
- Reverse diagonal tension crack, 16
- Reverse horizontal shear crack, 22
- Reverse vertical shear crack, 20
- Reverse vertical tension crack-1, 11
- Reverse vertical tension crack-2, 12

Seismic diagonal tension crack, 17
Seismic horizontal shear crack, 23
Seismic vertical tension crack, 14
Moletrack pattern, 41, 42, 46, 47

N

Nomenclature, 3, 5

O

Occurrence, 8, 39
Orientation in slabs, 7
 Oblique, 7
 Parallel, 7
 Radial, 7
Orientation in walls, 6
 Diagonal, 6
 Horizontal, 6
 Vertical, 6
Origin, 39
Overprinting, 49

P

Parallel closure, 46
Parallel pattern, 41, 42, 46
Patterns, 1, 40
Plural lineament, 40, 45
Probability, 44, 46
Propagation, 40, 41

R

Radial pattern, 41, 42

CRACK PATTERNS IN BUILDINGS

S

- Sawtooth pattern, 41, 42
- Separation, 43, 44, 55
- Singular lineament, 40, 44
- Slab crack orientation, 7
- Slope creep, 6
- Soil-structure interaction, 8, 50, 55, 61
- Stairstep pattern, 41, 42, 44
- Stepover pattern, 41, 42, 44
- Strain, 39
- Stress, type of, 7
 - Compression, 7
 - Shear, 7
 - Tension, 7
- Subordinate displacement, 41, 42
- Subsidence, 6, 42
- Sympathetic cracks, 52

T

- Terminated closure, 40, 43, 45
- Texture, 44, 46
- Trace, 40, 41, 43, 44, 46

V

- Vertical plane, 6

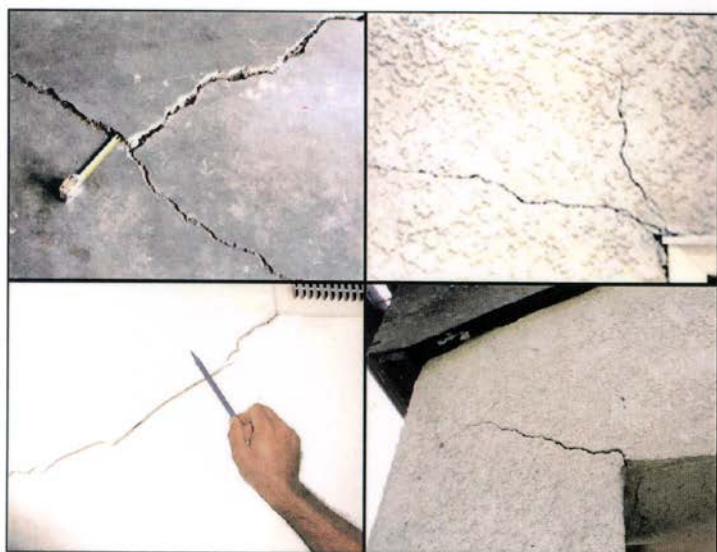
W

- Wall crack orientation, 6
- Weathering, 45, 46



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