DISTINGUISHING BETWEEN EARTHQUAKE DAMAGE AND OTHER CONDITIONS

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SUMMARY

Distinguishing between recent earthquake damage and pre-existing distressed conditions is often not as simple as it first appears and requires careful field observation, understanding of structural behavior, understanding of the construction and inspection process, and consideration of other relevant items. Conclusions as to what is new earthquake damage or exacerbation of pre-existing damage should be based on sufficient reliable information. Developing this information may require that detailed field investigation and analytical studies be performed. In this paper, several case studies are presented to show factors that should be considered when trying to distinguish between recent earthquake damage and other conditions.

INTRODUCTION

After earthquakes, engineers are often asked to identify and evaluate recent earthquake damage for building owners, insurance companies, government agencies, or attorneys. Though it is obvious that earthquakes are but one of many factors capable of causing distress to building structures and finishes, distinguishing between the effects of earthquakes and the distress caused by other factors is not always a simple process, particularly for buildings with an unusual, archaic, or highly redundant structural system. This task can be even further complicated when buildings have experienced one or more earthquakes prior to the most recent event, each of which may have superposed distress on the structural and nonstructural systems.

In some circumstances, while it may be expedient for an engineer to conclude that all observed distress is earthquake-related, either by causation or exacerbation, in actuality it is a rare existing building indeed whose distress can all be attributed to an earthquake. Engineers who are retained to evaluate buildings after an earthquake would do well to remember that large portions of the inventory of existing buildings in many countries have never experienced significant ground shaking, but these buildings regularly experience distress, or exhibit evidence of aging or construction related abnormalities. It should be clear, but often seems to be forgotten that in asserting that a particular condition was caused by a recent earthquake, the engineer is positively identifying that earthquake as <u>the</u> cause for that condition. Since the phrasing does not admit of other possible causes, the engineer needs to have developed sufficient reliable data to preclude other possible causes. Make no mistake --- in alleging that the earthquake caused the distress the engineer is affirming that the earthquake is more than just a possible cause for the distress.

This argument, trivial though it may seem, can be extended to positions taken by some engineers with regard to exacerbation of pre-existing distress. In our experience, engineers often simultaneously make seemingly contradictory claims that all observed distress was caused by the recent earthquake, and that any unspecified pre-existing distress that may have existed was also made worse by the earthquake. Again, it ought to be clear but is often forgotten by some engineers that for the exacerbation argument to be plausible, sufficient reliable data needs to have been developed to form an engineering basis about the extent or degree of the pre-existing distress. In short, if the engineer is to argue for example that a crack in concrete got wider or longer during an earthquake, then he ought to have specific objective data enabling a comparison between the crack widths or lengths before

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and after the earthquake. Engineers should approach post-earthquake damage evaluation as scientists using hard objective data. Simply stated then, post-earthquake damage evaluations ought to include in addition to identification of earthquake damage, a rationally based identification of distress that is not related to any earthquake, and/or of distress that is related to some previous earthquake, and to do this requires an understanding of what types of loading the building has been subjected to in the past, the intensity of those loads, and the response of the building and its finishes to those loadings. These tasks can be complex and can require significant effort to complete. Oftentimes therefore, in addition to developing a basis for comparing the intensity of shaking due to different earthquakes, a post-earthquake damage evaluation will also require that the history of the response of the building to a variety of regimens other than earthquake also be developed. For many types of structures and structural materials, this may require consideration of environmental factors and/or a detailed familiarity with construction methods. Oftentimes it further requires that the engineer take the time to look beneath the surface --- to practice what we call engineering archeology --- and expose the history of the distress and repairs in the building. We will illustrate some of these points in the following case studies.

The Need to Understand and Consider Construction Processes

Perhaps the most visible recent illustration of confusion between earthquake-related damage and pre-existing conditions concerns the discovery of planar ultrasonic indications in the roots of many hundreds of full-penetration welds in welded steel moment frame buildings in the Los Angeles area after the 1994 Northridge earthquake. These planar indications were defined as W1's by SAC and were almost universally accepted as phenomena that resulted from the earthquake (SAC 1995). Millions of dollars were spent to find them and tens of millions more to repair them, and to this day WSMF buildings remain stigmatized by the waves of technical and lay publicity alleging that hundreds of them were severely damaged during Northridge. Now, however, it is understood, though not yet widely known, that W1's are artifacts of construction that were not identified by ultrasonic inspection at the time of construction and that the actual number of WSMF buildings that experienced significant weld fracturing during Northridge is but a small fraction of the total number of WSMF buildings in the shaken area (Paret and Attalla, 1998; Paret, 2000). Unfortunately, the stigma will probably never be erased.

In this case, the confusion between construction related defects and earthquake damage was clearly caused by the lack of familiarity on the part of most design engineers with welding procedures, construction processes, and inspection capabilities, and compounded by the willingness of some engineers to rely on simplistic assumptions that have little or no basis in fact. It is wrong to state pseudo-aphorisms like "welds in a building should be free of large discontinuities and slag inclusions because the engineer called for 100% inspection in the construction drawings" if you do not understand the fine points of welded steel frame construction and inspection. It is wrong to allow unsubstantiated assumptions to invade the scientific method that ought to be the basis for all post-earthquake damage evaluations.

The Need To Consider The Normal Behavior Of Structural Systems Under The Influence Of Loading Regimens Other Than Earthquake.

Case Study 1

Is there any doubt that post-tensioned 1960's parking garage construction with prestressed "T" and post-tensioned slabs and cast-in-place shearwalls --- prior to the advent of elastomeric bearing pads and prior to modern shearwall location plans intended to minimize horizontal restraint --- regularly experienced diagonal cracking in the shearwalls, slabs, and "T" beam stems due to long-term creep and shrinkage induced slab and beam shortening? We are surprised at how often diagonal cracking in concrete is wrongly attributed to earthquake shaking, even in structures that provide ample cause for concluding that cracking occurred for other reasons. Though it is true that diagonal cracking in concrete is a common occurrence during earthquakes, in our experience a great number of buildings exhibit diagonal cracking that displays a signature that is inconsistent with earthquake loading. Remembering that cracking in concrete is a phenomenon that preserves for later evaluation the orientation of the state of stress (as well as some threshold value for the intensity of the state of stress) in the structure at the instant of cracking, it can readily be seen that only the basic tools of engineering mechanics need be used to identify the orientation of loads that were on the structure at the instant of cracking. In performing an earthquake damage evaluation in a structure with diagonal cracking, the engineer is required to determine if the orientation of loading at the instant of cracking is consistent with the orientation of loading that can reasonably be considered to have occurred during the earthquake. Diagonal cracking that is symmetrically splayed as opposed to forming x-cracking (due to cyclic load reversals) or being uniformly oriented (due to response to a pulse), for example, is oftentimes not readily attributable to earthquake shaking if the engineer is held to using rational methods founded on generally accepted principles of earthquake engineering and engineering mechanics. To return to a typical example of a post-tensioned structure from the 1960's, and setting aside the fact that cracking in the pattern shown (Figure 1) regularly occurs in similar structures in non-seismic regions, it is difficult indeed to conceive of how an earthquake could have caused these cracks. The pattern of diagonal cracks in the wall on the west end of the frame line is consistent with a horizontal force toward the east, while the pattern of diagonal cracks in the wall on the east end of the frame line is consistent with a horizontal force toward the west. The most rational explanation for each of these walls having cracked in a diagonally symmetric pattern is that they cracked in response to the post-tensioning induced shortening of the slab and prestressed "T". The absence of cracking in the wall near the centerline of the structure also attests to the absence of any relationship between the observed cracks and earthquake shaking. Only shortening of the slab could have left the end walls cracked as they have, and have left the center wall uncracked.

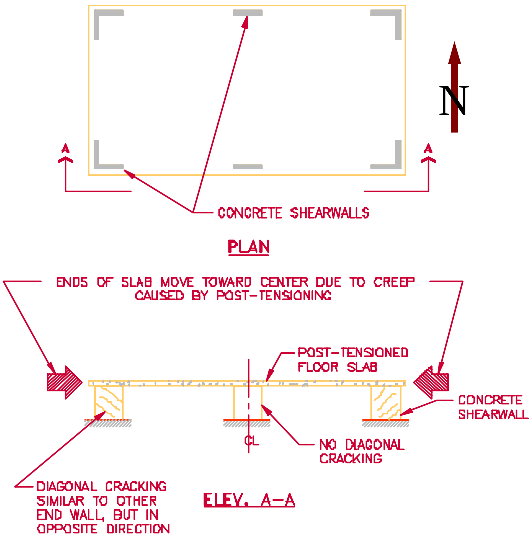

Figure 1

Case Study 2

As another example of non-earthquake related splayed cracking in walls, Figure 2 describes a multi-story wall-beam supported vertically at approximately two quarter-points by reinforced concrete pylons and cantilevered beyond. The openings in the wall-beam, which are doorways, are not shown in the figure. The wall-beam also resists lateral forces above the third floor, but transfers them through the third floor diaphragm to other walls. The crack pattern observed after the Northridge earthquake --- splayed about each pylon and symmetric about the wall centerline --- is also shown in the figure. The original post-earthquake investigators --- seeing extensive diagonal cracking --- quickly concluded that extensive damage had been caused by the earthquake. The investigator then confirmed this finding via a response spectrum analysis (RSA) of a coarsely meshed finite element model, which showed that higher shear stresses generally occurred in the lower floors and nearest the pylons. However, the investigator failed to recognize among other things that a response spectrum analysis cannot predict crack orientation since RSA turns all stresses positive. Subsequent step-by-step static analysis involving both monotonic and superposition of opposite-direction monotonic loading demonstrated what is intuitively obvious --- the crack pattern observed is unrelated to horizontal loading. Instead, the pattern of diagonal cracks results from vertical forces due to gravity, concentration of gravity-induced stresses in the lower stories as a result of construction sequencing, and substantial upward redistribution of gravity-induced stresses as the wall in the lower stories cracked.

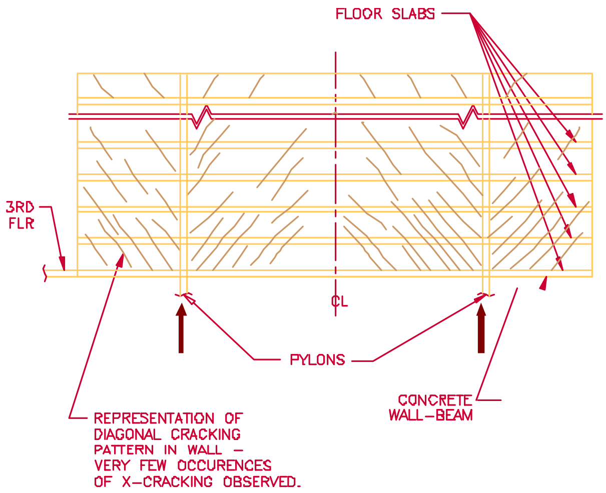

Figure 2: Elevation of Wall-Beam (not to scale)

The Practice of Engineering Archeology

Engineers have traditionally delved under the surface of structural behavior using analytical techniques which can reveal the underlying characteristics of a structure that control its response to load. However, there are many times when the results of analytical studies are sufficiently ambiguous to leave unresolved fundamental questions about the origins of observed distress. When confronted with these cases, we attempt to supplement the analytically available data through the practice of engineering archeology, and oftentimes these supplementary archeological studies either resolve the analytical ambiguity or answer by themselves questions about when particular items of observed distress appeared. By knowing when certain distress became manifest, an engineer can sometimes make great strides toward identifying the cause of the distress.

We have found engineering archeology to be a particularly useful tool for resolving questions about whether certain cracking in concrete structures was caused by recent earthquake ground shaking, but we have also practiced it, for example, to re-define the origins of W1's in welded steel moment frames as described earlier. On numerous projects when cursory examination of concrete elements might have suggested to a post-earthquake investigator that observed cracking is earthquake related, we have employed archeological methods and found unmistakable evidence of multiple repairs to nonstructural finishes directly associated with the distressed concrete. (Figures 3 and 4) In these instances, the only conclusion that makes sense is that the distress in the concrete was caused prior to the most recent ground shaking event, either due to a previous earthquake or due to other loads, and was cosmetically repaired multiple times. The physical evidence shows that those repairs were intermittently ruptured and repaired again. This knowledge is invaluable to an investigator evaluating how the structure performed during a particular earthquake. If only previous repairs to nonstructural finishes became damaged in the earthquake, then it can be concluded, perhaps, that the structure performed quite differently than if widespread distress occurred in the structure for the first time. There are many methods available for digging beneath the surface to extract data of this sort, but whichever method or methods are utilized on a particular project, care must be taken to adhere to the principle of scientific objectivity. With proper care, the physical history of distress and repair in many structures can be systematically exposed and with this history the cause of the distress can likely be identified with far more certainty than exclusive reliance on any analytical method.

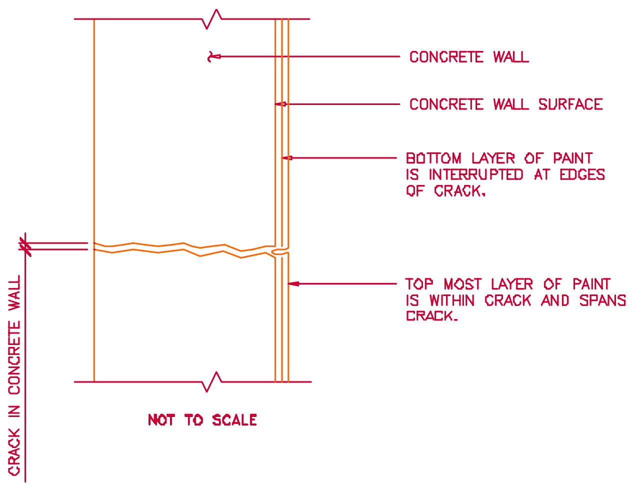

Figure 3: Wall Section - Paint within Crack

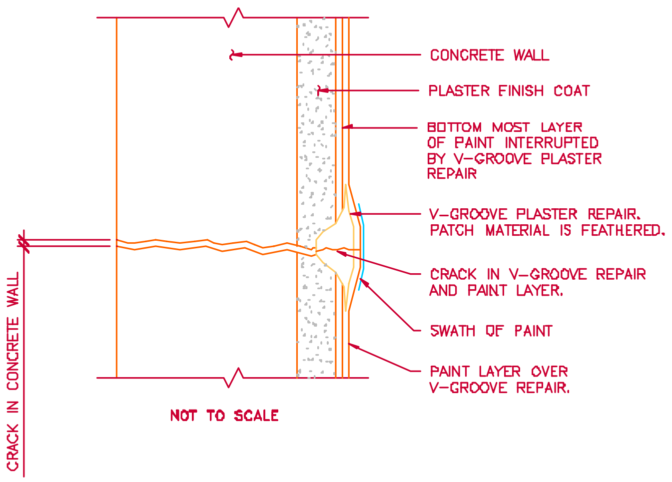

Figure 4: Wall Section - Multiple Cosmetic Repairs

CONCLUSIONS

Distinguishing between earthquake damage and other conditions is oftentimes not a simple process. Pre-existing distress conditions caused by non-earthquake loading regimes or previous earthquakes may be present. Also, pre-existing distress caused by non-earthquake loading may, upon initial observation, appear to be earthquake-related. Therefore, post-earthquake investigators whose charge it is to identify new earthquake damage need to consider pre-existing distress conditions and the forces or factors that caused them. Conclusions as to what is new earthquake damage or exacerbation of pre-existing damage should be based on sufficient reliable information. Developing this information may require that detailed field investigation and analytical studies be performed.

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