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REPAIR OF EARTHQUAKE DAMAGED BUILDINGS

by

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SUMMARY

A thorough analysis of an earthquake damaged structure must be made before repairs and strengthening work can be designed and executed. First, the earthquake damage must be thoroughly investigated and the causes for the damage determined. Repairs for the damage can then be designed together with any desired strengthening to prevent a recurrence of the damage in the next earthquake. The consequences of the strengthening scheme must then be investigated in detail to insure that it does not in turn become the cause of further damaging effects. Several examples are cited.

INTRODUCTION

After all damaging earthquakes, there is a great desire by building owners to get their buildings repaired and back into operation as soon as possible. Frequently, building owners or local building or government officials will also desire or require that the building be strengthened to provide increased lateral force resistance for preparation of the next earthquake. This paper attempts to outline a procedure for this strengthening and warn of several potential pitfalls frequently observed.

DETERMINING THE DAMAGE CONDITION

The first step in repairing any earthquake damaged structure is determining exactly how the structure performed. This requires a detailed inspection of the building and a listing of all damaged elements and members. It may be necessary to open concealed areas to permit a thorough investigation and insure that hidden damage does not remain undetermined.

The engineer must then analyze the structure and thoroughly understand why the damage occurred. He must satisfy himself of the force resistant paths in the building and why certain members failed or cracked while other members were essentially undamaged. He must determine if members failed due to shear, compression, tension, flexure, bar anchorage, etc. He must consider the effects of non-structural elements such as walls and parapets. This analysis is essential before any repairs can be designed.

DESIGN OF STRENGTHENING SCHEME

Once the damage is documented and understood, the repair of individual members can be designed to return the original or desired strength to the member. Such repairs usually consist of epoxy injection, partial replacement or occasionally, complete replacement of the damaged member.

The engineer then needs to consider how to minimize such damage in the future. He may decide to strengthen selected members which failed and make them considerably stronger. He may decide to add shear walls to stiffen a frame structure. He may replace damaged non-structural walls with structural bracing walls.

Whatever strengthening techniques are chosen, the effects of the strengthened members on adjacent members and the total structural system must be investigated. If certain frame members are made stronger, will the next earthquake simply cause the adjacent unstrengthened member to fail? If a wall element is introduced, will it cause adjacent failures due to overturning forces or stress transfers? If strengthening is added in only one story of a building, will it cause increased damage in other stories of the building which were undamaged in the recent earthquake? The following section provides several examples.

SELECTED EXAMPLES

The first example involves the Colegio Teresiano on the outskirts of Managua, Nicaragua. The building is a three story concrete frame school building of a long rectangular plan, similar to schools built throughout the world. A small earthquake of magnitude 4.6 in 1968 was centered quite close to the building and caused cracking and structural distress to the columns in the first story. The building was repaired by adding a stiffened concrete wall element in the first story between classroom doors and extending up to the second floor balcony rail height. This new wall element can be seen in Figure 1.

The destructive Managua earthquake of December 23, 1972, caused considerable damage to this building, but only in the second and third floors, where considerable column damage resulted. Figure 1 was taken after this second earthquake. The new wall elements in the first floor prevented damage in that floor, but permitted the earthquake forces and motion to travel upward, causing the observed damage. The repairs had not considered the effect on the remainder of the structure. Had these or stronger walls extended to the roof, much of this damage might have been prevented.

A second example shows a three story classroom building at the Agricultural University in the La Molina area of Lima, Peru. There are four identical buildings of concrete construction. The first story was originally framed without structural walls and only columns for support and bracing. Considerable wall panels and masonry partitions were present in the upper two stories. A magnitude 7.5 earthquake on October 17, 1966, caused significant damage to the first story columns, so concrete shear panels were introduced to stiffen and brace this first story.

A second earthquake of magnitude 7.6 affected these structures on October 3, 1974. Figure 2 shows the end of one of these buildings after that earthquake. There was little damage in the first story due to the previous strengthening, but that increased stiffness caused considerable damage in the upper two floors which had not been strengthened after the 1966 earthquake.

CONCLUSIONS

The damage sustained by a structure in an earthquake must be thoroughly understood and analyzed before repairs can be designed. Repairs which involve adding strength or stiffness to a member or structure must be fully analyzed for the impact on adjacent members or stories in future earthquakes.

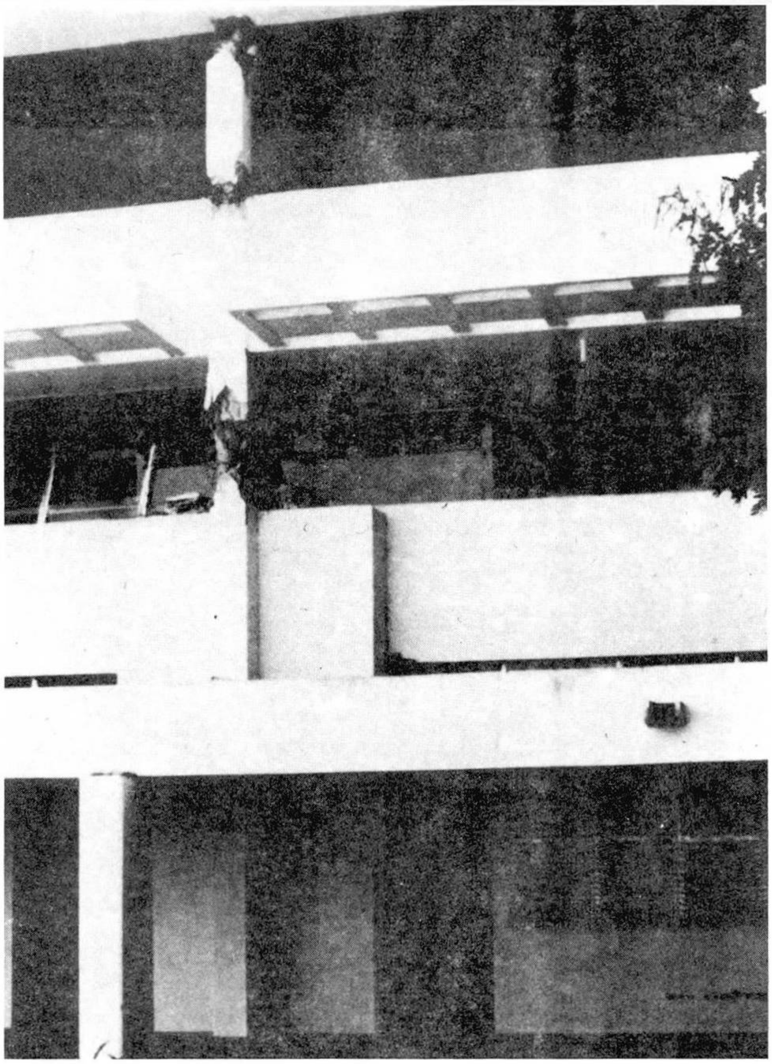

Figure 1. Colegio Teresiano in Managua, Nicaragua, after 1972 earthquake. First story stiffening wall, which can be seen projecting outward from second floor beam, prevented first story damage but increased upper story damage.

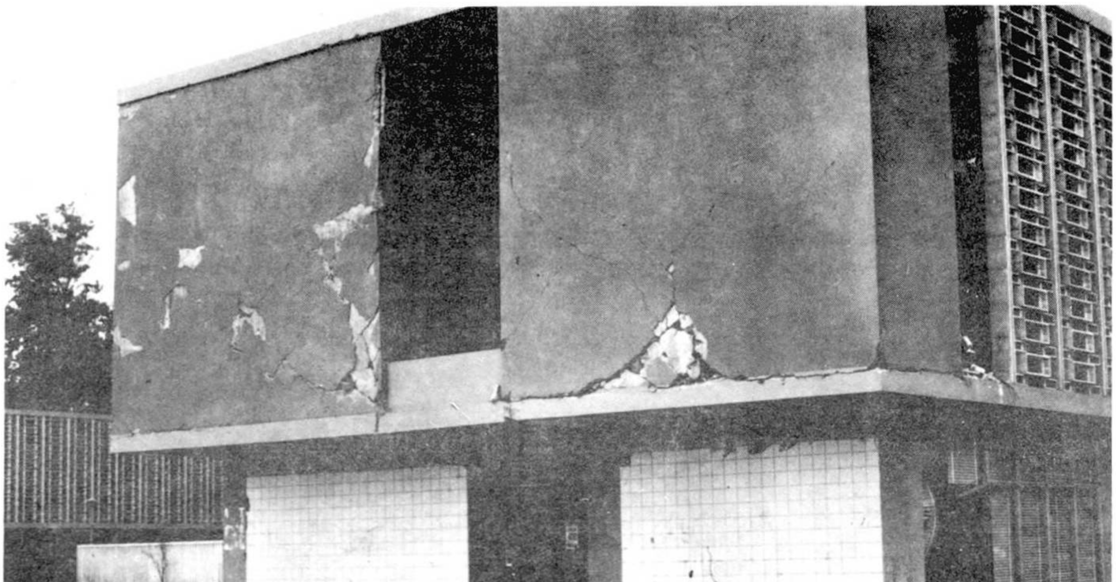

Figure 2. Classroom building at Agricultural University after 1974 earthquake. Stiffened first story had little damage due to added concrete wall panels, but upper stories had increased damage in this earthquake.