THE MAY 6, 1976, FRIULI - EARTHQUAKE ASSESSMENT AND INTERPRETATION OF BUILDING DAMAGE

Presentation by

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Despite the most tragic consequences of an earthquake, much can be learnt from an exhaustive investigation of earthquake damage. The earthquake specialists assembled at the second international UNESCO-Conference in Paris were of the unanimous opinion that a better theoretical understanding of the effects of earthquakes can be achieved only by thorough observation of the effects of the natural phenomenon itself. In this area, field work is considered to be an irreplaceable prerequisite for the advancement of knowledge aiming at effectively reducing the immeasurable losses of future earthquakes.

The building damage caused by the May 6 Friuli-Earthquake was therefore of much interest for engineers daily confronted in their jobs with the structural problems of earthquake safety. The area, which had much construction activity over the past years, was expected to provide an abundance of illustrative material. It was unthinkable to miss the rare opportunity of examining on the spot the ultimate carrying capacity of diverse types of structures all of which had been damaged or destroyed by the same occurrence. The following were the aims of the expedition:

- Critical examination of the earthquake characteristics together with their effects on the earth surface;
- Inspection of typical structural damage and destruction, particularly ultimate carrying capacity.

A great deal of information and documentation was collected, including notes on conversations, sketches, several hundred photographs and newspaper clippings, which, together with the participants' own impressions formed a richly documented, far reaching report for those authorities directly interested.

A detailed summary of the report which I have mentioned was published in German in the Swiss Construction Magazine (Schweizerische Bauzeitung) on September 16, 1976.

A Few General Remarks on Earthquake Behaviour of Buildings

A closer examination of the effects of the earthquake on various types of structures reveals that much of the damage originates from just a few basic structural defects. We have tried to derive several ground rules for the design of structures. Although these conclusions can also largely be confirmed by observation of other earthquakes, the damage described here is peculiar to this particular earthquake and epicentral region.

The main cause of the extensive damage is certainly the fact that the effects of an earthquake did not have to and therefore were not taken into consideration in the design of the buildings. If engineers had only visualized that their structures would have to undergo the displacement, velocity and acceleration of earthquakes, the few selfevident consequences in the layout of the structures would have avoided most of the damage even without a proper earthquake design.

STRUCTURAL ELEMENTS

Walls

Walls and partitions consisting of brick and masonry are both rigid and brittle. Where the walls are insufficiently strong or where many openings exist, the masonry walls are no longer able to absorb horizontal forces. When overstrained, these walls crack mostly crosswise under 45° (Figure 1), the cracks spreading, either along the mortar joints or in the bricks. Because of the brittle nature of masonry constructions, the cracks widen, joints gape open or the walls concerned even collapse. In a skeleton construction, the reinforced concrete framework can in certain cases continue to uphold the weight of the buildings. For purely masonry construction, on the other hand, at least a partial collapse of the building is unavoidable.

Reinforced Concrete Columns

Since reinforced concrete columns are, in general, considerably more flexible than walls, the latter carry practically the entire earthquake force. However, in open constructions the entire stress is carried by the columns. The free-standing reinforced concrete columns of one-storey storage sheds were mostly strong enough to absorb the stress without being destroyed, in many cases even without incurring lasting cracks. By partial stiffening, for instance by means of an annex or installations or heavy rigid upper floors, higher stress results, which usually leads to plastic deformation at both ends of the columns. Hence, the reinforcement, overstressed by tension, can buckle as a result of the alternating action (Figure 2). The related cracking of the concrete and the buckling cannot be significantly reduced even by means of closely spaced stirrups.

The ability of the resulting plastic joint to rotate is, however, increased and a sheer failure prevented.

In the event that it is impossible to design the columns, taking actual earthquake forces into consideration, then at least the plastic deformation of the columns in all directions must be guaranteed. The movements should not be hindered by any secondary elements. An improved building method for the prevention of collaps could, therefore, be to shape the columns in a manner that the plastic hinges, necessary to absorb energy, are formed in the crossbeams.

STRUCTURAL SYSTEMS

Open Ground Floors

Open or only slightly stiffened ground floors, mostly for commercial use, are particularly vulnerable. The locally severe destruction in the area of such weak spots caused the collapse of entire buildings or made their demolition necessary, even with otherwise only minor damage, because restoration would have been too difficult (Figure 3).

Greatly differing conditions of rigidity in a supporting structure result in local weak spots which are the first to be overstrained in an earthquake and plastically deformed. Hence the stronger parts of the building are no longer irreversibly deformed and energy absorption is limited to the weakest building parts. Consequently, an evenly distributed plastification of the entire structure is necessary to ensure that destruction remains within acceptable limits.

Torsional Action

From the point of view of the structural system, many symmetrical structures suffered damage due to the additional twisting motion of the building around its vertical axis. As a result of the superimposed movement, some parts of the building are relieved whilst others are considerably more deformed than they would be due to translational movements only. Torsional loads are caused by the unsymmetrical layout of the structural system, but also by contingencies arising in the rigidity and execution of partitioning walls and additional fittings (Figure 4). The consequences of torsional strain can only be met by appropriate consideration in the design including provision for sufficient torsional rigidity of the building. Due to the incalculable influcence of secondary elements, which are not designed to carry vertical loads, an asymmetry in the ground plan can hardly be excluded.

Attached Buildings

Severe damage could be located in structures composed of building sections with greatly differing rigidity due to diverse types of construction (for instance, reinforced concrete frame and pure brick) or which varied considerably in their design (Figure 5). This damage occurred because the individual deformation of each component was obstructed.

This problem can be overcome by so arranging the joints as to divide the structure into sections, each with its own clearly distinct vibration behaviour. The joints should be made adequately wide since numerous uncertainties make an exact calculation impossible. It must be taken into consideration that, for example, the deformation usually provided for in a homogenous supporting structure can turn out to be considerably larger due to the formation of cracks or plastification. An adequate freedom of movement, therefore, allows for greater plastification and a larger capacity to carry earthquake stress.

Special Structures

Special structures (e. g., bridges and water towers) (Figure 6), because of their unusual form and distribution of mass, necessitate a dynamic analysis which takes the vibration behaviour of the structure and the real properties of an anticipated earthquake into consideration.

Secondary Structural Elements

All the components and fixtures, in particular dividing walls, attached façade slabs, coverings, pipes and other fittings, which form part of a structure, influence the response of the supporting structure (Figure 7). These secondary structural elements are generally not included in the analysis of the supporting structure and, therefore, not designed against earthquake forces. They can, even when subjected to only slight movements, suffer damage which produces an increasing alteration in the vibration behaviour. It cannot be predicted whether this influcence will prove to be positive due to greater absorption of energy or negative due, for example, to added torsional motion. As far as possible, in order to ensure that secondary elements survive earthquake loads without substantial damage, they should be analysed and designed together with the supporting system.

JOINTS AND SUPPORTS

Joining of Structural Elements

If prefabricated structures are designed only in accordance with the Standards laid down for earthquake forces or these forces are overlooked altogether, then the result is greatly underdimensioned connexions of the structural elements. Load bearing connexions should be properly designed against the expected dynamic forces. Purely friction-type joints are no longer sufficient to transfer the forces that arise, even from only weak earthquake loads (Figure 8).

Fixation of Secondary Structural Elements

Building parts (such as prefabricated façade slabs and dividing walls and fittings, particularly machines, storage racks and pipes), which are not part of the supporting structure, are usually either directly or indirectly connected to it. Due to the action of the earthquake, much damage occurred through the displacement or collapse of façade slabs which were unconnected or insufficiently secured (Figure 9). The actual displacement occurring at the fixation point, which can be considerably larger than the one of the ground shock, must be taken into consideration in the fixation of secondary elements.

Bridge Bearings

As opposed to the old stone arch bridges, a good number of newly erected reinforced concrete bridges incurred damage which was chiefly limited to the bearings and abutments (Figure 10). From the point of view of mass arrangements, bridge constructions come under the heading of special structures, since here the generally heavy girders in beam and slab bridges rest on comparatively high and therefore flexible piers. It is impossible to achieve with conventional methods a stabilization of the huge mass forces that occur when the structure is subjected to earthquake shocks. It should be noted that the reinforced concrete bridges hit by the earthquake in Friuli suffered severe damage which will be difficult to repair, but they were by no means in danger to collapse.

MERITS AND LIMITS OF EARTHQUAKE DESIGN SPECIFICATIONS

The region at the southern foot of the Alps hit by the May 6th earthquake has been known for centuries as an earthquake area. However, in the major part of the epicentral area, no laws existed for the design of structures. Such laws applied only for new buildings in a small part of the area.

The Italian State Administration has enacted special regulations for earthquake-prone areas and has repeatedly brought them up-to-date. Using the Code, design earthquake loads are determined by statical or dynamic analysis. An average horizontal acceleration will result, which is about 7 percent of the gravity acceleration g. Comparison of horizontal design accelerations given by the Code with those produced by an earthquake with the Intensity IX (Figure 11) shows large discrepancies.

The Code values are significantly smaller because it is assumed that strong energy absorption will occur due to inelastic behaviour of materials and elements. But this means that the structure must be capable of absorbing the appropriate energy. Consequently, plastic deformation and therefore damage or maybe even collapse can result.

On present day standards, this is not good enough. Originally, Codes were drawn up merely to prevent the collapse of a structure and thus save lives. Today, our more highly developed society demands that at least life-lines (i. e., hospitals, water supplies, electricity, etc.) continue to function after an earthquake. As a result, it is imperative that a Code be introduced incorporating design specifications which distinguish between the various functions for which structures are built.

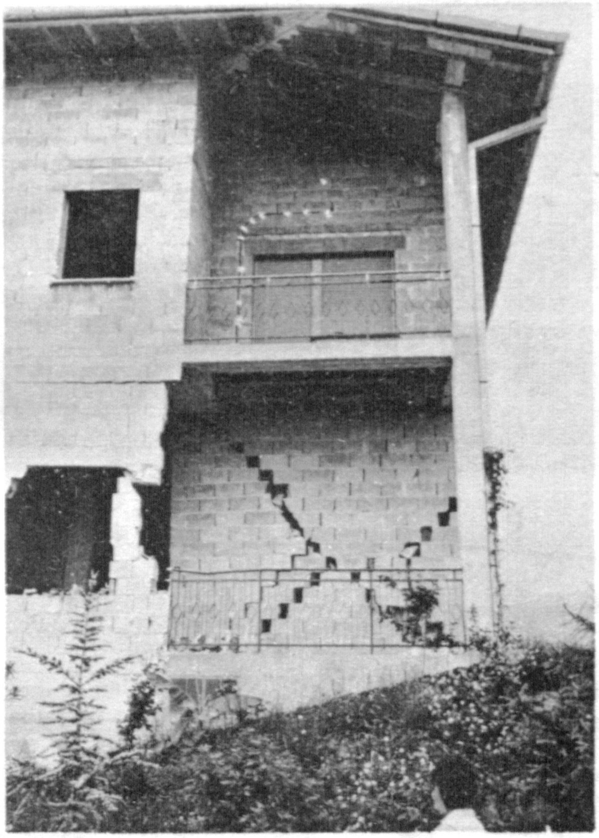
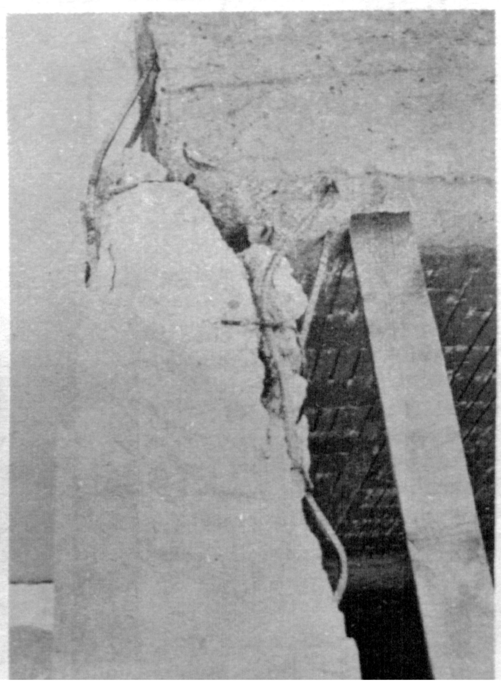


Figure 1
Dwelling house with workshop near Artegna. Basement in reinforced concrete and the upper stories in masoning without framing. Typical diagonal cross cracks in a wall of the ground floor.

Figure 2
Shearing-off of a column at its connection with the crossbrain due to insufficient stirrups.



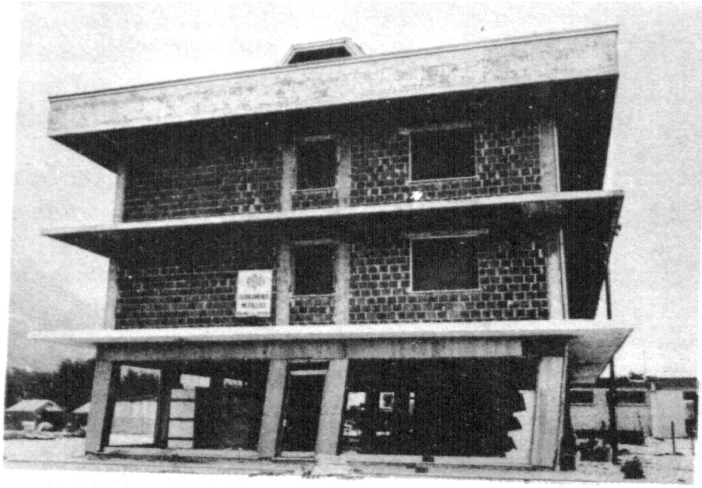


Figure 3

Three-storey dwelling house with shop in the ground floor near Artegna. Reinforced concrete frame with brick partitioning walls in the upper floors and mostly open ground floor. Plastic hinges at bottom and top of the ground floor reinforced concrete columns caused large deformations. No damage in the upper floors.

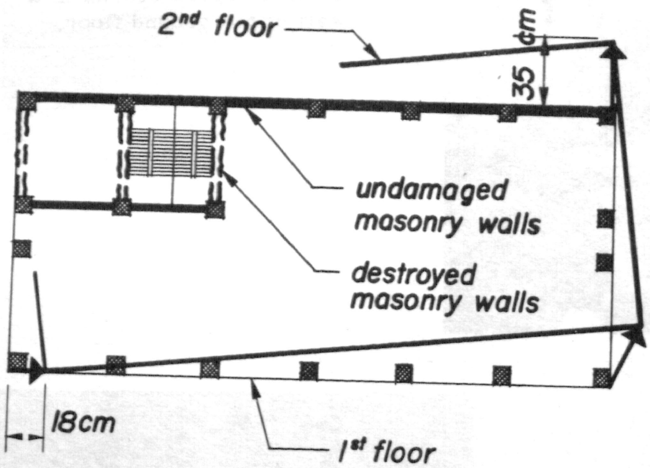


Figure 4

The ground plan of the dwelling house with the open ground floor shown before. Twisting of the buidling around the staircase stiffened with masonry walls.

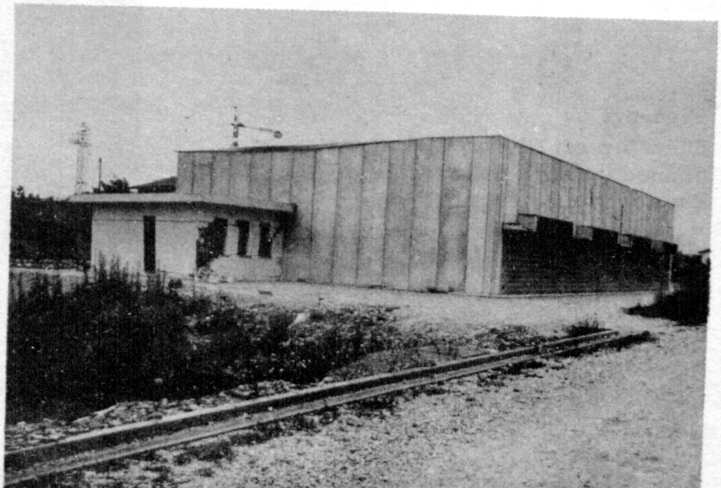


Figure 5

Prefabricated storage shed with brick annex in Gemona. Side wall panels slightly caved in by impact with rigid annex. Upper part of the annex shorn off and pushed over by the impact force due to insufficiently wide joints.

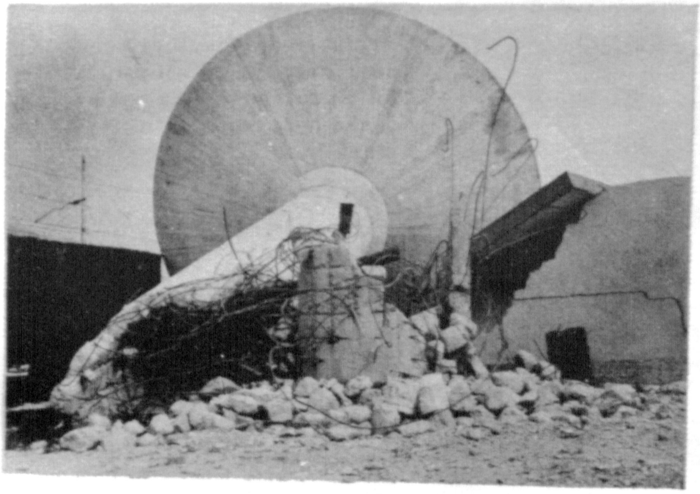


Figure 6

Overturned water tower belonging to the Italian State Railways in Gemona station. Foot of the shaft completely destroyed and concrete shattered.

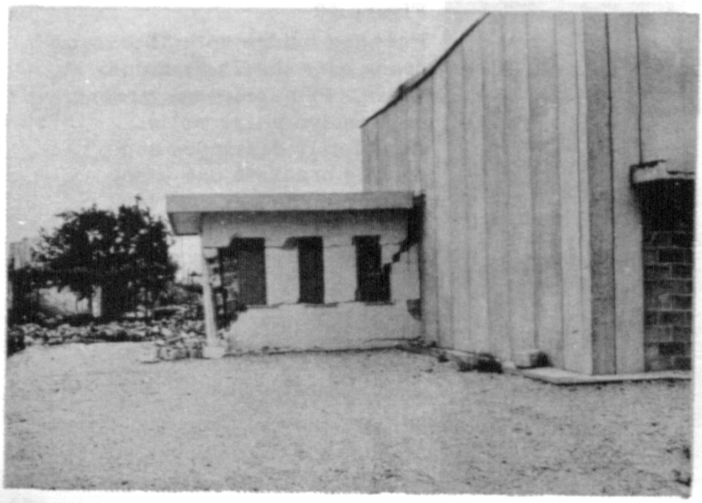


Figure 7

Prefabricated storage shed in Gemona as shown before. The supporting frames and the wall panels generally not damaged because of energy absorption in the material of the joints between the single panels.

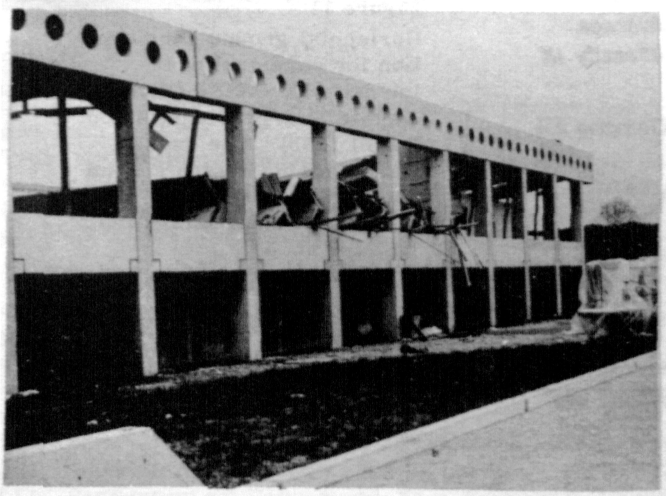


Figure 8

Heavily damaged prefabricated factory shed near Osoppo with roof girders fallen down. Friction joints insufficient to provide structural stability.

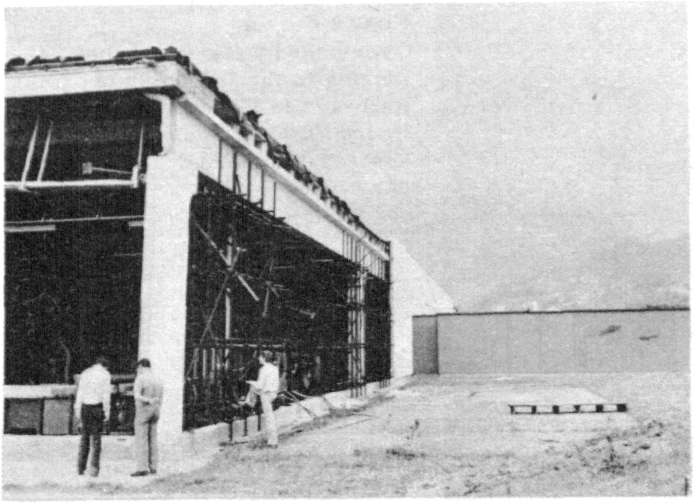


Figure 9
Prefabricated factory shed near Artegna. Wall panels fallen out during the earthquake because of insufficient fixation.

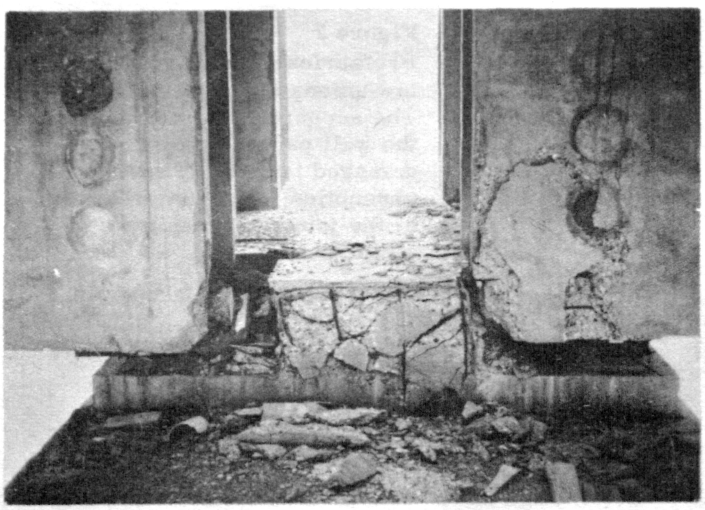


Figure 10
Freeway bridge with 32 spans over the Tagliamento River. Prefabricated girders on massive pillar walls. Completely destroyed supporting brackets due to the impact of the girder. Left bridge girder slipped from its bearing.

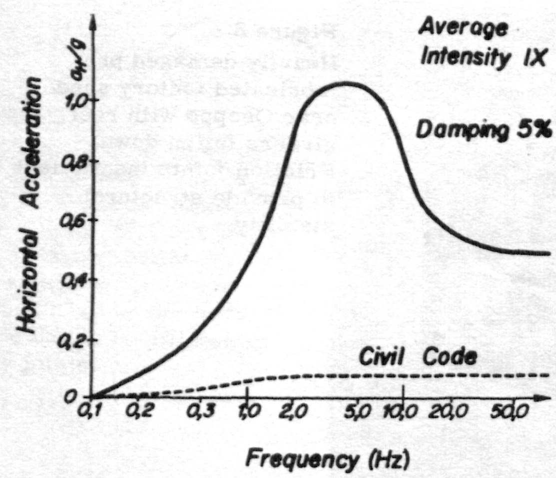


Figure 11
Horizontal ground acceleration for earthquakes of intensity IX (MSK) (U. S. Atomic Energy Commission, WASH 1255). The dashed line gives the design ground acceleration according to the conventional aseismic building code.