Chapter 3

STRUCTURAL EFFECTS OF THE AGADIR EARTHQUAKE

INTRODUCTION

PAST earthquakes have contributed greatly to technical knowledge about how structures behave under load, particularly with regard to the effects of lateral inertia forces. In a sense, an earthquake in a populated area may be considered as a mammoth structural test program in which the performance of various types of construction and of different forms of structural details may be compared. Earthquakes have an uncanny ability to seek out the weak design or construction features in a structure, and study of the effects of earthquakes brings home forcefully the truth of the old adage that "a chain is no stronger than its weakest link." The keys to successful design of earthquake resistant structures are: visualization of the inertia forces engendered in the structure by the earthquake accelerations, and planning of a direct and simple structural path by means of which these forces may be carried down to the foundations.

In addition, a structure should be tied together in all respects so that the total structure may respond to earthquake ground motions as a unit. When a structure is vibrated, stiff elements are sought out, and any lack in uniformity, strength, ductility and reliability of the materials of the resisting elements, or in the integrity of the design and/or construction, are soon brought to light. Therefore, in addition to providing a sound structural system, the structure should incorporate ductile materials which are tough and have energy-absorbing qualities which can withstand dynamic forces without fracture.

One example of the above comments, noted at the dock area, was a stiff brittle end wall, without ductility and strength, which fractured and was rendered useless, while interior steel bents which were ductile, tough and strong remained completely unaffected by the shock.

The Agadir earthquake did not provide a particularly effective structural test of seismic resistance. Due to the fact that there had been no recent destructive seismic activity in Morocco, earthquake forces had not been considered in structural design, and only a small percentage of the structures had been designed even for wind forces. Consequently, the structures in Agadir, in general, did not have that degree of earthquake resistance which can be included at a reasonable extra cost, assuming that the basic design for vertical loads is sound and carefully executed and seismic concepts are understood and carried out.

In Agadir, as has been observed at the scene of other earthquakes, the variations in structural damage from district to district were extremely great. Two basic factors contributed to this variation in performance:

1. Distance from the epicenter. Because of the shallow focus and relatively small magnitude of this earthquake, the amplitude of ground accelerations diminished rapidly with distance from the epicenter, and structures at a radius of more than five kilometers were not shaken severely.
2. Quality and type of construction. The extent to which a structure was tied together was reflected quite directly in its performance. Where the elements were merely piled one on another, like a house of cards, the ground vibrations in the epicentral zone generally caused complete collapse. On the other hand, where the floors and walls, columns and beams, etc., were tied together so that they might act effectively as a unit, performance was generally fair, even in the areas of maximum seismic intensity.

Structural Types Observed

Construction in Agadir was of several types, and general observations may be made with regard to the performance of each type (although exceptions to any generalization may be noted, in this as in past earthquakes). The most prevalent construction was masonry. The masonry structures actually covered a wide range of types, but only two will be distinguished here. The first type to be noted is the old, poor quality, stone masonry construction characteristic of dwellings in the Kasbah, Founti, and Yachech districts. In these buildings, the mortar generally was of mud and sand; roofs varied from timber rafters covered with corrugated sheet iron to reinforced concrete slabs. The structures usually were one or two stories in height.

The second type of masonry structure will be designated as modern masonry, although it cannot be compared with the reinforced masonry used in some modern construction. These structures were found throughout the greater part of the Talborjt district and also in the newer districts. In most cases, they were three or four stories in height, and frequently had a smooth plaster finish over the masonry, giving them the appearance of modern buildings. However, under the plaster, the structures were found to consist of unreinforced masonry bearing walls and partitions, supporting concrete slab floors and roofs. The masonry was either of stone or clay tile; the mortar varied from weak mud and sand to good quality sand-cement.

The other principal type of construction in Agadir was reinforced concrete. One type had concrete columns and beams for carrying vertical load, but the joints between these members lacked moment as well as shear resistance which might serve to resist lateral forces. In a second type, the columns and beams were joined rigidly into an integral structural system. In both types of concrete structures, walls and partitions generally were of masonry; in the first type, however, these masonry filler walls provided the only resistance to lateral forces, while in the second type the structural frame contributed to the lateral force resistance and helped to tie the structure together.

Besides the masonry and the reinforced concrete beam and column type structures, there were a few special structures in Agadir worthy of note. The performance, during the Agadir earthquake, of each class and type of construction as well as some special structures, will be discussed in the following sections of this chapter.

MASONRY STRUCTURES

The stone masonry structures in the Kasbah, Founti, and Yachech districts were responsible for a large share of the deaths and injuries which resulted from the earthquake. In these districts which were close to the epicenter, nearly 100 per cent of the structures were damaged beyond repair and most collapsed completely. Figs. 15 through 19 show the destruction which occurred in the Yachech district to this class of construction; similar effects were observed in the Kasbah and Founti districts as well. The sharp, sudden jolt generated by this nearby earthquake focus was particularly effective in wrecking these brittle, rigid structures. The structures had little capacity for yielding or for energy absorption; in most cases the first cracking was concurrent with the complete collapse of the structure.

In Yachech, the steep hillside location compounded the destructive effects of the earthquake. Houses high on the hills collapsed on the structures below, precipitating a chain-reaction effect. The poor quality of the mortar used in this construction is evidenced as shown in all

Fig. 15. Collapse of Old Masonry Construction, Yachech District

Fig. 16. General View of Yachech District

Fig. 17. Typical Street Scene, Yachech District

Fig. 18. A Comparison of Damage in the Yachech District

of these photographs by the way the walls disintegrated completely as they collapsed. The stones simply fell apart, the cementing effect of the mortar was almost nil. The Army bulldozers seen in Figs. 18 and 19 were sent into the Yachech and Kasbah districts after rescue operations were terminated. Their function was to break down the few walls which remained standing and level off and seal cavities in the debris in order to eliminate a potential hazard to the decontaminating teams which were operating in these districts.

An interesting comparison is presented in Fig. 18 in which the flimsy wooden shacks in the foreground show no apparent effects of the earthquake, while the presumably more substantial stone structures in the rear are seen in all stages of collapse. This is a graphic illustration of the fact that it is not merely the apparent strength of a structure, but rather its true strength in relation to its weight which controls its earthquake resistance. On this basis, the poor performance of these masonry structures is not surprising.

Fig. 19. Leveling the Ruins as a Safety Precaution

Although the newer masonry structures (found largely in the Talborjt district) generally were constructed with better quality mortar than was used in the older buildings, and some slight improvement could be noted in their performance as a result, the net gain was not very important. Ninety per cent of the structures in the Talborjt were damaged beyond repair.

The typical masonry structure of the Talborjt district was an apartment house of from two to four stories. Most of these were finished with a smooth layer of plaster on the outside, giving them the general appearance of reinforced concrete. Examples of typical damages suffered by this type of construction are presented in FIGS. 20 through 36.

In FIG. 20 is shown a classic example of the earthquake performance of the so-called "modern masonry" structure. The front wall of this structure has collapsed, exposing its internal construction. The earthquake hazard to people in the street presented by this type of construction is very clear. FIG. 21 shows the same street after the bulldozers have cleared a path through it. Building facades on both sides of the street show how plaster has been used to give a smooth surface over the rough masonry structure.

Examples of damage to clay tile masonry structures are shown in FIGS. 22 and 23. It appears that no significant improvement in performance is provided by this modern wall filler material, even though the clay tile produces a lighter weight structure than stone. The hollow cellular floor construction in the building shown at the left in FIG. 23 appears to be very lightly reinforced. The building at the right in FIG. 22 is presented in a closer view in FIG. 24. The upper two stories of this structure appear to

Fig. 21. Scene After Street Has Been Cleared by Bulldozers

Fig. 22. Collapse of "Modern Appearing" Masonry Construction, Talborjt District

Fig. 23. Close-up of Ruins Shown in Fig. 22

Fig. 20. Typical Failure of Masonry Construction, Talborjt District

Fig. 24. Complete Collapse of First Story of Building Shown in Fig. 22

be relatively undamaged, but a close inspection reveals that the first story has collapsed completely.

FIGS. 25 through 29 show the effect of the earthquake on the modern-appearing masonry bearing wall structure of the Lyautey Hospital. In FIG. 25, the diagonal cracks between the windows of the one story portion of the structure to the right are noteworthy in that they are inclined only in one direction: upper left to lower right. This indicates that the primary ground shock was toward the left and rear in this photograph, i.e. toward the northwest. Evidence from many other damaged structures in Agadir indicated this same direction of primary ground motion.

The relative lack of damage to the spiral stairway and bridge structure shown in FIG. 26 is of interest because one might expect that such structures would be particularly vulnerable to earthquake damage. However, it was necessary for the designer to provide adequate reinforcing and continuity in these structures in order that they might resist static, vertical load. Thus, even though lateral forces may not have been considered in their design, they had a basic requisite of an earthquake resistant structure, i.e. they were well tied together. The performance of these and similar examples throughout the city demonstrated that it is not impossible to design structures to resist accelerations such as were produced in the Agadir earthquake; in fact, they tend to indicate that the magnitude of the ground accelerations developed here was not extremely great.

The opposite side of the main hospital structure is shown in FIG. 27. The wing which collapsed was the maternity ward of the hospital. Fortunately, it stood for 15 minutes after the earthquake, allowing time for its evacuation before the final collapse, and no one was injured in the failure of this structure. FIG. 28 is a closer view of the same structure, showing the

Fig. 25. General View of Lyautey Hospital; Note Diagonal Cracks in Masonry

Fig. 26. Lyautey Hospital; Bridge Structure and Spiral Stairway in Good Condition

Fig. 27. Collapsed Maternity Wing, Lyautey Hospital

Fig. 28. Close-up of Collapse; Note Lack of Connection to Adjacent Structure

Fig. 29. Remains of Maternity Wing