U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

RECONNAISSANCE REPORT ON THE 12 OCTOBER 1992 DAHSHUR, EGYPT, EARTHQUAKE

by

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SUMMARY

The 12 October 1992 earthquake (M_B 5.9; M_s 5.2) that occurred near the village of Dahshur, Egypt, was the latest in a long history of earthquakes that occasionally cause damage to buildings in Cairo and surrounding areas in northeastern Egypt. The epicenter of the earthquake was about 18 km south of the center of Cairo and located at a depth of about 25 km. Damage to engineered buildings in Cairo appeared to be mainly due to poor construction materials, poor construction detailing, overloading of building columns beyond their design values, inferior workmanship, or deficient foundation systems. Damage to non-engineered structures, such as dwellings, was substantial in the earthquake region, particularly for adobe construction. Adobe is known to be one of the most vulnerable building materials to earthquake shaking; widespread use of this material in villages along the Nile valley contributed significantly to the high number of deaths and injuries from this moderate-sized earthquake. Inspections of bridges across the Nile and overpasses in Cairo revealed no earthquake damage.

Geologic effects of the earthquake were minimal, restricted to a small area of minor liquefaction near the village of Manshyat Fadil on the west side of the Nile, approximately 20 km south of the epicenter. The area of liquefaction coincided with the severest shaking damage from the earthquake in Manshyat Fadil. Field investigations by motor vehicles and by airplane revealed no surface fault rupture from the earthquake.

That more widespread damage did not occur in the Cairo metropolitan area was due to the moderate size of this earthquake. However, considerable vulnerability to earthquake shaking exists in the Cairo building stock and far more severe effects would be expected from a somewhat larger earthquake in the vicinity of Cairo, or from an earthquake of comparable magnitude directly under the city. The important lesson learned from this earthquake was not of a technical or scientific nature. Rather, it was the tragic demonstration of the potential for catastrophe in metropolitan Cairo if the warning of this moderate earthquake is not heeded in future development, planning, and earthquake preparedness.

With this lesson in mind, we offer the subsequent recommendations on an earthquake preparedness strategy for the region affected by the 12 October 1992 Dahshur, Egypt, earthquake. They are divided into three categories: A) Engineering design and building code development, B) Scientific and engineering research needs, and C) Civil preparedness and governmental disaster response.

A. Engineering Design and Building-Code Development:

An earthquake itself does not pose a significant threat to people. Rather, it is the damage to, and collapse of buildings and other structures that result in casualties and fatalities. If construction practices are improved so that buildings withstand the expected earthquake ground motions with less damage and without collapse, lives will be saved and the number of injuries will be reduced. Much engineering knowledge has been gained from the study of earthquake effects on all types of construction around the world and the task of improving building construction and design begins with communicating this knowledge to local authorities and the local engineering community. Significant improvement to the earthquake resistance of common structures, such as dwellings, can be made with little additional cost if proper construction techniques are used.

A lasting contribution to improved earthquake-resistant design for all types of construction is to formalize appropriate earthquake-resistant construction techniques into a building code. Equitable application of building-code requirements throughout a region follows a scheme of zoning based on the prevalent earthquake ground-motion hazard. Thus, the ground-motion hazard needs to be quantified in hazard maps for rational decisions to be made on the degree of earthquake resistance that is required of construction in any particular area. Seismic-hazard maps of this type have also found wide-spread use in land-use planning and insurance analyses.

Recommendations in this category are aimed at near-term objectives (approximately three years or less to realize results) to deal with the immediate earthquake information needs of the practicing engineers and government agencies charged with overseeing construction practice. The recommendations, in large part, implement common knowledge that has been gained from earthquake experiences around the world.

1. Establish an influential task force consisting of knowledgeable engineers, seismologists, and geologists from various sectors -- academic, private, government -- to motivate professional and governmental concern and understanding of earthquake mitigation measures. Such a body could form the core group of a local professional organization promoting earthquake education and governmental earthquake-mitigation policy.

2. Quantify the earthquake ground-motion hazard throughout Egypt, with particular attention to northeastern Egypt and the vicinity of Cairo, in terms useful to modern engineering design and code development, land-use and economic planning.

3. Qualitatively establish the vulnerability of various types of common, high-occupancy construction in Cairo to earthquake shaking for estimates of earthquake risk (monetary loss) from past or potential earthquakes.

4. Establish earthquake-engineering-related curricula in the university system and encourage faculty and engineering students to become involved in all aspects of earthquake mitigation engineering including earthquake reconnaissance, recovery and reconstruction.

5 Conduct fora for exchanging information. Most observed damage to engineered buildings in the Dahshur earthquake was due to poor detailing and/or quality control. Commonly known errors made during design and construction of earthquake resistant structures could be avoided with simple communication/education vehicles, such as workshops and professional meetings, in which experts are brought together with practicing engineers and local authorities to exchange information on "lessons learned" from past earthquakes.

6. Provide guidance and education for non-engineered construction to the general public through information campaigns (see C below).

7. The General Authority for Roads and Bridges should adopt established standards for the retrofit of bridges and overpasses.

B. Scientific and Engineering Research Needs:

While the immediate needs in A above make use of "lessons learned" and data gained from past earthquake experience worldwide, refinements of those generalities specifically for application to Cairo and northeastern Egypt can only come from intensive engineering and scientific data collection in the region. This is the only way to test with certainty that the generalized engineering/scientific principles applied in the short term are indeed accounting for any peculiarities of construction and physical setting of Cairo and the northeastern Egypt region. The alternative method is to wait for the next large earthquake and leave verification to chance. In view of the current experience, this second approach is not satisfactory. Results from some of the recommended activities may not be realized for years, as in the case of strong ground-motion instrumentation and monitoring because results of this activity are dependent upon the occurrence of an earthquake large enough to shake buildings. However, without such data, verification of the safety measures implemented in the short-term will not be possible. Data base development is emphasized and it is assumed that concomitant analysis of the collected data will add to the engineering/scientific knowledge needed for improved local earthquake mitigation standards and strategies. Properly maintained, upgraded, and augmented instrumentation for collection of the much needed data is an immediate need.

1. Assure maintenance of existing earthquake recording/monitoring equipment that is already in-place by maintaining supplies of spare parts and calibration/repair equipment.

2. Upgrade and augment the existing permanent seismograph network for better coverage of the Cairo area and the populated Nile valley, including the El Faiyum area. The overall dynamic range of the network needs to be increased and the network needs to be broadened for better geographic coverage and epicentral locations.

3. Establish a strong-motion recording network in and around the Cairo metropolitan area using both free-field instrumentation and building instrumentation. Acquisition of strong-motion data for engineering use is a necessity. Buildings for instrumentation should be carefully selected to assure the broadest applicability of the data to numerous high-occupancy buildings of similar construction. Free-field stations should be carefully selected to sample ground motions in the predominant soil types and thicknesses throughout the city.

4. Begin systematic identification and study of faults having geologically youthful movements in the vicinity of Cairo and in the populated Nile delta region. Develop tectonic models that relate contemporary movements on these faults to the regional tectonic regime, including their relation to active extensional tectonism occurring to the east in the Gulf of Suez.

5. Compile data bases of geotechnical engineering data for soil types and thicknesses throughout Cairo. Theoretical studies of possible sites of ground-motion amplification and locations of possible ground failure and liquefaction could be made as a short-term "solution" to these hazards due to lack of recorded data.

6. In the longer-term, with the collection of ground-motion data, validate the assumptions made in the foregoing earthquake hazard and risk studies and establish ground-motion attenuation properties for earthquake sources and soil types specific to the northeastern Egypt region.

7. Quantify experimentally the vulnerability of high-occupancy building types in the Cairo metropolitan area to earthquake shaking.

C. Civil Preparedness and Governmental Response:

This is a very broad category that includes activities ranging from distributing educational brochures to the general public to motivating the organization of a governmental body charged with disaster preparedness and response. As such, levels of commitment also range from very short term (brochures) to long term (developing comprehensive emergency response plans). With respect to earthquakes, the lasting effect of short-term tasks is questionable because they rely primarily on educating the public while, it is known that social memory is short. As time passes, the occurrence of an earthquake and its effects are largely forgotten by the time a similar earthquake occurs during the next "uneducated" generation. The education process then starts anew. This is not to say that such educational efforts are not worthwhile, only that some continuing effort is always required to keep the "lessons learned" from being forgotten. Such efforts can be as simple as assuring press and television coverage of earthquakes that occur in other parts of the world or instituting an "earthquake safety week" in the schools. A professional organization, as suggested in section A above, can be charged with publicizing and organizing such activities. Perhaps most important to preparedness plans, however, is realizing that it is the first few hours following the earthquake that are critical to saving lives. In a large earthquake, medical facilities and governmental agencies will be strained to their limits and it is the "grass roots" training and organization of the general public that will largely result in saved lives. The following recommendations are not intended to be a comprehensive list of activities to develop emergency preparedness and response plans. They are mostly the initial reactions and thoughts of the reconnaissance group members to what they saw in the aftermath of the Dahshur earthquake.

1. For non-engineered construction in rural areas, provide guidance and education regarding construction of dwellings through readily available brochures showing simple methods of improving a simple structure's resistance to lateral movement (see Chapter V). Discourage the use of adobe as a building material and encourage the use of good mortar and masonry. This is a lesson that has been learned far too many times -- adobe is the worst building material to use in earthquake-prone areas because of its extremely high vulnerability to earthquake shaking.

2. Provide readily available brochures to the public on what to do in an earthquake. Above all, caution the public not to panic. Reportedly, deaths occurred in the Dahshur earthquake from school children running for the exit, trampling their classmates. Teach earthquake safety and preparedness in the schools. Include instructions regarding simple methods of "earthquake-proofing" the home.

3. Establish emergency medical training for village authorities similar to Red Cross training so first-aid care can be given to the injured immediately following the earthquake. Ensure adequate local stocks of first-aid medical supplies.

4. Identify beforehand local buildings to be used as emergency shelters. In Girza, the reconnaissance team observed that the most substantial building in the village, a reinforced concrete-framed school, was closed because it was deemed unsafe when only a parapet fell and the walls had minor cracks. No structural damage was apparent. Many people in the village were without shelter because of damage to, or destruction of, their homes and a good many

others were still living in seriously damaged adobe dwellings. The suggestion was made that the remaining parapet be remove or braced so it would not fall in aftershocks, and that the school be used for shelter of the homeless and those still living in seriously damaged dwellings.

5. In the metropolitan area of Cairo, organize the professional practicing engineers to perform building safety inspections throughout the city following an earthquake. California has a very successful program along these lines which could serve as model. Once again, a professional organization as suggested in A above, could organize such a team of professionals to assist government agencies in the aftermath of an earthquake.

6. Educate appropriate officials regarding modern techniques of search and rescue. Often times expert groups are brought in from the U.S. or European countries to perform search and rescue. However, if local officials are not aware of procedures, much harm can be done within the hours prior to the arrival of the rescue teams and valuable time is lost waiting for others. Much valuable experience was gained from the earthquake in 1985 that devastated high-rise construction in Mexico City, Mexico. Lessons learned there do not need to be relearned in a city such as Cairo.

7. Establish contingency plans for the removal of the critically injured by air from the villages along the Nile. Limited highway access to these villages along each side of the river, and no river crossings south of Helwan, could greatly hamper rescue and response efforts in this area. If significant liquefaction destroys one highway (as was observed at Manshyat Fadil from the 12 October earthquake) access can be blocked to villages along one side of the Nile valley for up to 100 km south of Cairo.

RECONNAISSANCE REPORT ON THE 12 OCTOBER 1992 DAHSHUR, EGYPT, EARTHQUAKE

I. INTRODUCTION

On October 12, 1992, the region of Egypt in and around Cairo experienced a moderate earthquake of magnitude M_B 5.9 (M_s 5.2) centered near the village of Dahshur that resulted in an estimated 541 people killed, in excess of 6,500 injured, roughly 8,300 buildings damaged or destroyed, and an estimated $300 million loss in physical damage (from the National Earthquake Information Service, NEIS, obtained from the Foreign Broadcast Service). By invitation of the Government of Egypt (GOE) and through the sponsorship of the United States Agency for International Development (USAID), reconnaissance team members arrived in Cairo on October 21, 1992. Investigations of the reconnaissance team were, (1) assessment of the level of shaking and damage effects in areas of Cairo and in villages along the valley of the Nile, (2) assessment of damage and serviceability of bridges and barrages along the Nile River, (3) assessment of the available seismological information regarding the Dahshur earthquake, its aftershocks, and historical earthquakes of northern Egypt in general, and (4) identification and investigation of surface fault rupture and geologic effects that may have accompanied the earthquake. The USAID-sponsored team coordinated with the engineering investigation team sponsored by the Earthquake Engineering Research Institute to ensure that all scientific aspects of the earthquake, as well as the concerns of the GOE and USAID, were addressed in the investigations.

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Thenhaus, Sharp and Ibrahim addressed geological, seismological and seismic intensity aspects of the earthquake. Celebi and van de Pol addressed engineering issues related to building and bridge/barrage performance, respectively. This report is organized into three sections after the specialties of the team members. Chapters III and IV by Thenhaus, Sharp and Ibrahim addresses seismological and geological aspects of the investigations. Chapter V by Celebi concerns engineering aspects of building construction and performance and Chapter VI by van de Pol addresses aspects of bridge and barrage construction and performance.

III. HISTORICAL EARTHQUAKES

Northeastern Egypt, including the Cairo area, has been the site of a number of earthquakes since Biblical times. The contemporary geological setting of the region is governed, in large part, by active extensional tectonics taking place within the Gulf of Suez rift. For over twenty years, geologically young faulting has been known to exist both along the margins and within the Gulf of Suez. Reflecting this active geological setting, a relatively high rate of historical earthquake activity also characterizes the Gulf of Suez and continues on-trend to the northwest in a broad, diffuse pattern of activity (Figure 1). The earthquake of 12 October 1992 was not without historical precedent in northeastern Egypt. On August 7, 1847, an earthquake with an estimated magnitude of 6.8 occurred about 100 km southwest of Cairo, probably near El Faiyum. Three thousand houses and 42 mosques were destroyed in El Faiyum and damage was extensive in Cairo. Similarly, a large earthquake in the Mediterranean on July 24, 1870, caused damage in Alexandria, Cairo, Ismailia and the Nile delta region. Earthquakes in 1754, 1303, 1111, 887, among others, have caused damage in northeastern Egypt. Because earthquakes are generated by geological processes that operate on time scales of many millennia, it is inevitable that northeastern Egypt will again be subjected to strong earthquake shaking in the future. Because earthquakes cannot presently be predicted and will probably never be prevented, the best mitigation strategy is one of earthquake preparedness.

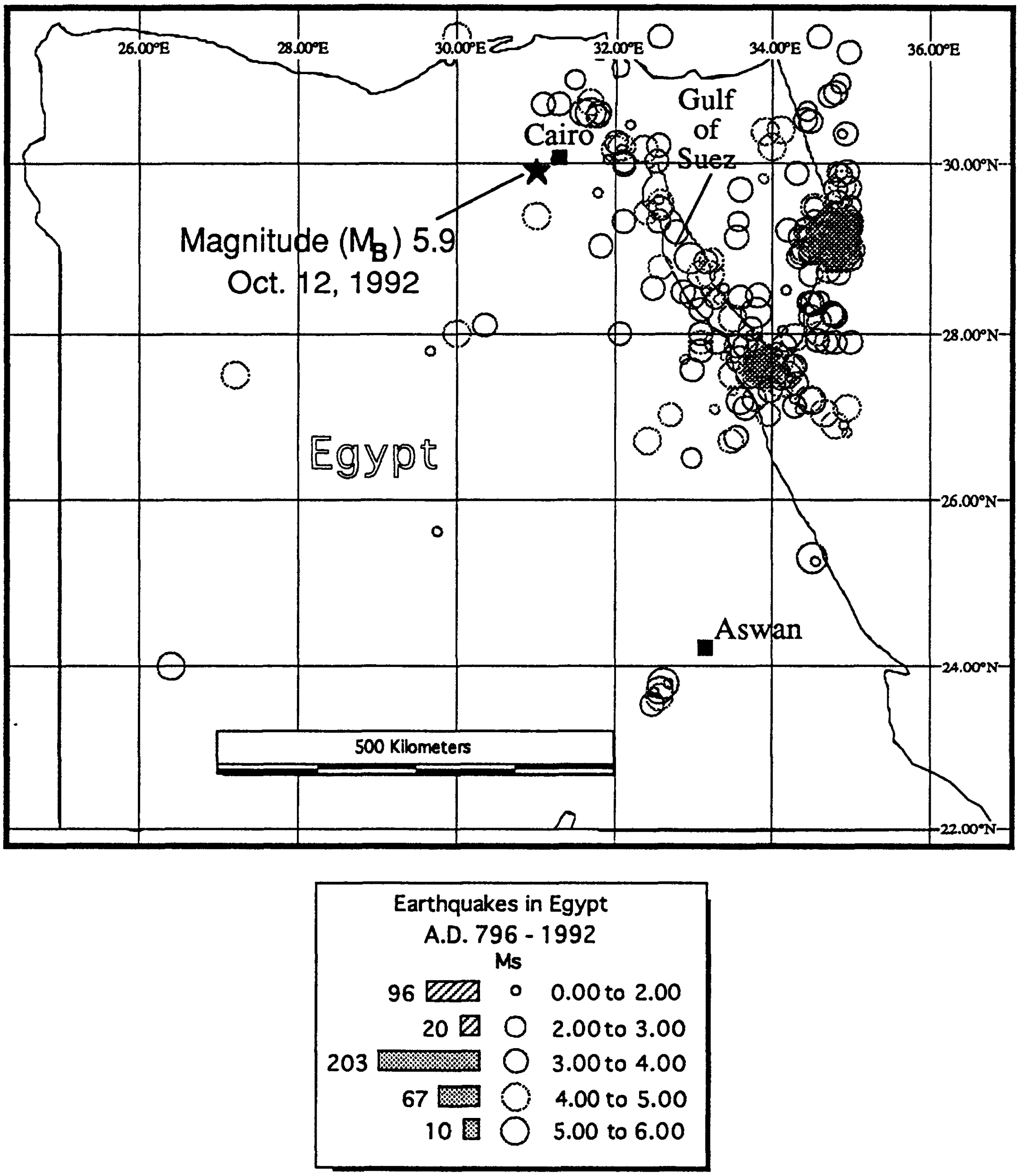


Figure 1. -- Distribution of earthquake epicenters in Egypt, A.D. 796 - 1992 (From the NEIS world data base of earthquakes.)

IV. INTENSITY DISTRIBUTION OF THE 12 OCTOBER 1992, DAHSHUR, EGYPT, EARTHQUAKE AND THE EARTHQUAKE SOURCE

Intensity Distribution

Figure 2 is a preliminary map of the Modified Mercalli intensity (MMI) distribution of the Dahshur earthquake. Areas of inspection were along Highway 2 on the west side of Nile River valley as far south as Girza; on the east, along Highway 54 as far south as Atfih; west along Highway 22 between Cairo and Lake Qarun; and in Cairo. The southern extent of the isoseismals is based on interviews with staff members of the Geological Survey of Egypt that are knowledgeable of earthquake effects in the villages of Tamiya, El Roda and El Faiyum. The smoothed contours of the isoseismal map represent the highest predominant levels of MMI with regard to building damage and, therefore, do not preclude isolated higher intensities and common lower intensities than the generalized level of intensity shown on the map. Intensity assessments were not based on geologic effects of the earthquake because of the known wide variation in the threshold shaking required to produce these effects and their strong dependence on local geotechnical properties of soils, water content, and degree of slope. The western and eastern excursions of the isoseismals are queried to reflect uncertainty in their locations in desert regions characterized by very low population concentrations and little development.

In general, MMI VII effects (see Table 1 for earthquake effects and their relative rankings in the MMI scale) were widespread in the villages of the Nile valley to approximately 80 km south of Cairo, which includes most of the populated area of the Giza governorship (Fig. 2). One- and two-story adobe dwellings performed poorly and were the primary cause of the more than 500 earthquake fatalities. Fallen adobe walls and collapsed roofs that had been supported by cross timbers were common. The considerable damage to adobe dwellings warranted MMI VII assessments at many villages in the Nile valley. Brick-firing kilns with masonry smoke stacks approximately 20 m to 30 m tall are scattered throughout the Nile valley but none was known to be toppled in the earthquake. Only one stack was observed to be cracked; it was near the village of Girza. This observation generally limits a maximum MMI assessment to some level lower than VIII for most of the affected area of the Nile valley. However, maximum MMI VIII effects were observed in the village of Manshiyat Fadil on the west side of the Nile River, approximately 20 km south of the National Earthquake Information Service epicenter at 29.89° N., 31.22° E. (PDE, 11/5/1992). The principal bases for this assessment were the fall of unreinforced masonry walls of dwellings and the more widespread damage and collapse in adobe dwellings than in nearby villages. Newer one- and two-story reinforced concrete-framed dwellings with masonry infill walls performed well with no damage or only hairline cracking at the contact of the concrete frame with the infill masonry wall. Two older dwellings of apparently similar construction were, however, severely cracked. Coincident with this intensity assessment, sandblows of a limited extent were observed in the cultivated fields neighboring Highway 2 just south of Manshiyat Fadil. The roadway itself reportedly settled 1.5 m along a distance of perhaps 100 m but was repaired and in use at the time of the inspection.

Inspections in the city of Cairo were primarily in the southern and eastern parts of the city. Thus, the exact location of the VI-VII contour through the city is somewhat uncertain. Slight to moderate cracking in the walls of multistory concrete-framed buildings was observed at scattered locations in south Cairo. At a few isolated locations, walls of dwellings of mixed construction

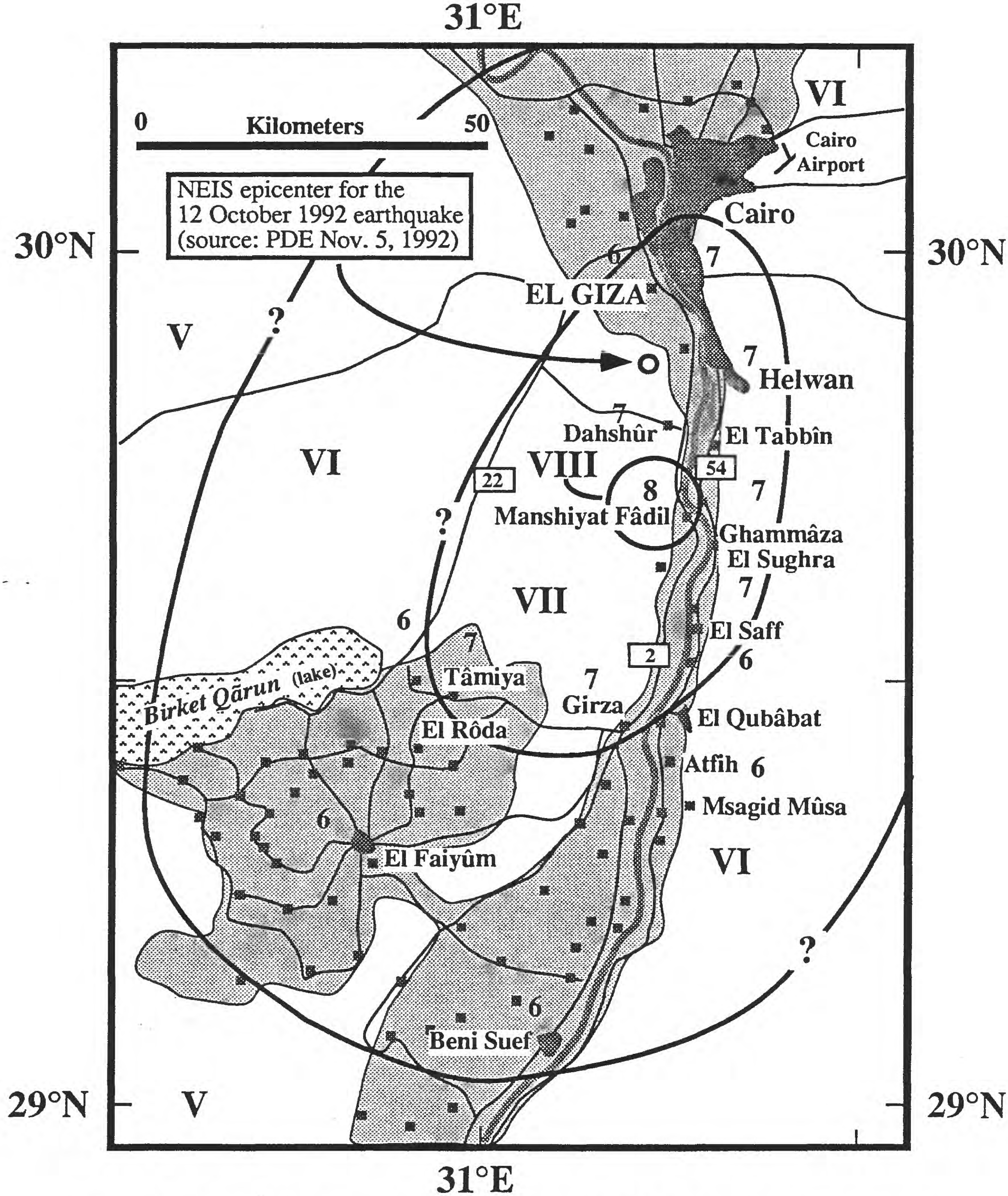


Figure2. -- Intensity distribution of the 12 October 1992, Dashûr, Egypt, earthquake. See text for explanation.

Table 1. The Modified Mercalli intensity scale (abbreviated). The modified Mercalli scale measures the intensity of ground shaking as determined from observations of an earthquake's effect on people, structures, and the Earth's surface. The scale assigns to earthquake effects a Roman numeral from I to XII as described in the table. In this investigation, modified Mercalli values were assessed only on building damage.

I	Not felt by people, except rarely under especially favorable circumstances.
II	Felt indoors only by persons at rest, especially on upper floors. Some hanging objects may swing.
III	Felt indoors by several. Hanging objects may swing slightly. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Felt indoors by many, outdoors by few. Hanging objects swing. Vibration like passing of heavy trucks; or sensation of a jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V	Felt indoors and outdoors by nearly everyone; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset; some dishes and glassware broken. Doors swing; shutters, pictures move. Pendulum clocks stop, start, change rate. Swaying of tall trees and poles sometimes noticed.
VI	Felt by all. Damage slight. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks and books fall off shelves; pictures off walls. Furniture moved or overturned. Weak plaster and masonry cracked.
VII	Difficult to stand. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in badly designed or poorly built buildings. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken. Damage to masonry; fall of plaster, loose bricks, stones, tiles, and unbraced parapets. Small slides and caving in along sand or gravel banks. Large bells ring.
VIII	People frightened. Damage slight in specially designed structures; considerable in ordinary substantial buildings, partial collapse; great in poorly built structures. Steering of automobiles affected. Damage or partial collapse to some masonry and stucco. Failure of some chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Damage considerable in specially designed structures; great in substantial buildings, with some collapse. General damage to foundations; frame structures, if not bolted, shifted off foundations and thrown out of plumb. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground; liquefaction.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, embankments. Landslides on river banks and steep slopes considerable. Water splashed onto banks of canals, rivers, lakes. Sand and mud shifted horizontally on beaches and flat land. Rails bent slightly.
XI	Few, if any masonry structures remain standing. Bridges destroyed. Broad fissures in ground; earth slumps and landslides widespread. Underground pipelines completely out of service. Rails bent greatly.
XII	Damage nearly total. Waves seen on ground surfaces. Large rock masses displaced. Lines of sight and level distorted. Objects thrown upward into the air.

(adobe/undressed stone/ masonry) collapsed with consequent collapse of the roof. Although some unreinforced masonry parapets had fallen, many more of apparently similar construction remained intact. This general degree of damage was taken to indicate a maximum predominant MMI VII. Also undamaged were many tall minarets and towers of mosques, and high stacks of industrial complexes in the vicinity of southern Cairo and Helwan. As in the Nile valley, these observations suggested an upper limit of intensity below VIII. The collapse of the 14-story, reinforced concrete-framed apartment structure in eastern Cairo would qualify for a site-specific MMI assessment of IX. However, this was an isolated case of the collapse of a substantial structure with engineering deficiencies (see Chapter V) and, therefore, was not given special consideration in the regional distribution of intensity.

The northeast-trending elongation of the isoseismals in Figure 2 is due to the north-trending belt of population and development along the Nile valley and the very sparse settlement of neighboring desert regions. The isoseismal shapes should not, therefore, be used to infer properties of a fault rupture, such as concentration of damage along strike of a hypothetical fault rupture or focusing of ground motion at the terminal ends of rupture. However, the fact that the highest damage was concentrated south of Cairo may be related to such fault-rupture properties and is discussed in the following section. Amplification of ground motions by alluvial deposits in the Nile valley may have contributed to the severity of damage there and, perhaps, also to the isolated pockets of damage in Cairo although amplification is difficult to identify with certainty without recordings of strong ground-motion.

The overall concentration and distribution of intensity is consistent with the distribution of injury and mortality rates resulting from the earthquake (Figure 3). The highest mortality rates (and absolute mortality numbers) were encountered in Giza (J. Malilay, Centers for Disease Control, written communication) and were probably concentrated in the villages of Giza along the Nile (as opposed to the urbanized area of northern Giza) based on the high degree of damage in these rural villages.

The Earthquake Source

Field investigations were undertaken to identify the causative fault and the nature of the crustal movement that generated the earthquake. The best information we now have on the epicentral coordinates, provided by NEIS, are latitude 29.89° N. and longitude 31.22° E, based on data from more than one hundred stations in the Worldwide Standard Seismograph Network (WWSSN). The focal depth below the land surface is estimated to be about 25 km. The ground location of the epicenter lies at the west edge of the Nile floodplain about 4 km north of the village of Saggara, some 18 km south of the center of Cairo.

Searches for earthquake related faulting were performed by helicopter and surface vehicles in the region around, but especially southwestward from the preliminary epicenter location by NEIS that was located about 11 km farther south in the vicinity near Dahshur. The approximate paths followed in this search are shown in Figure 4. Our search, as well as those by other groups known to us, has not yielded evidence of a fault dislocation visible on the ground surface.

The search strategy that we used was based on a preliminary moment tensor "focal mechanism" (a geometric evaluation of the orientation of the causative fault and the direction and

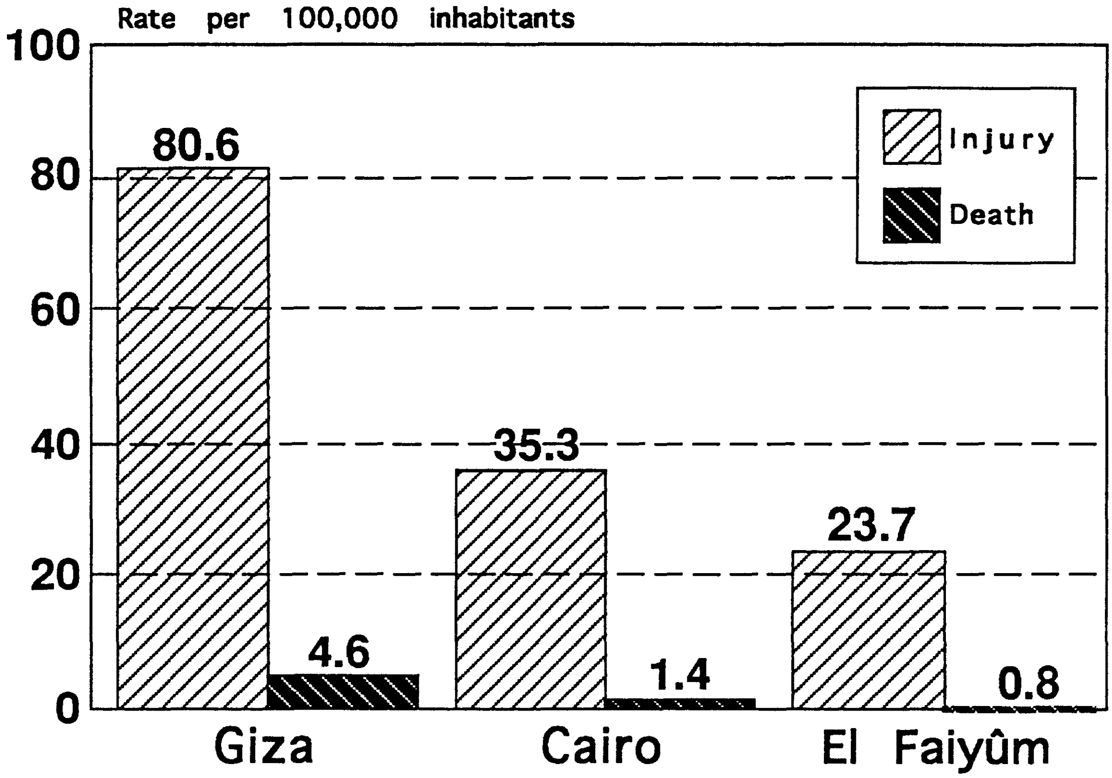


Figure3. -- Distribution of injuries and deaths for selected locations Dahshûr earthquake, Egypt, 12 October 1992. (Source: J. Malilay, Centers for Disease Control)

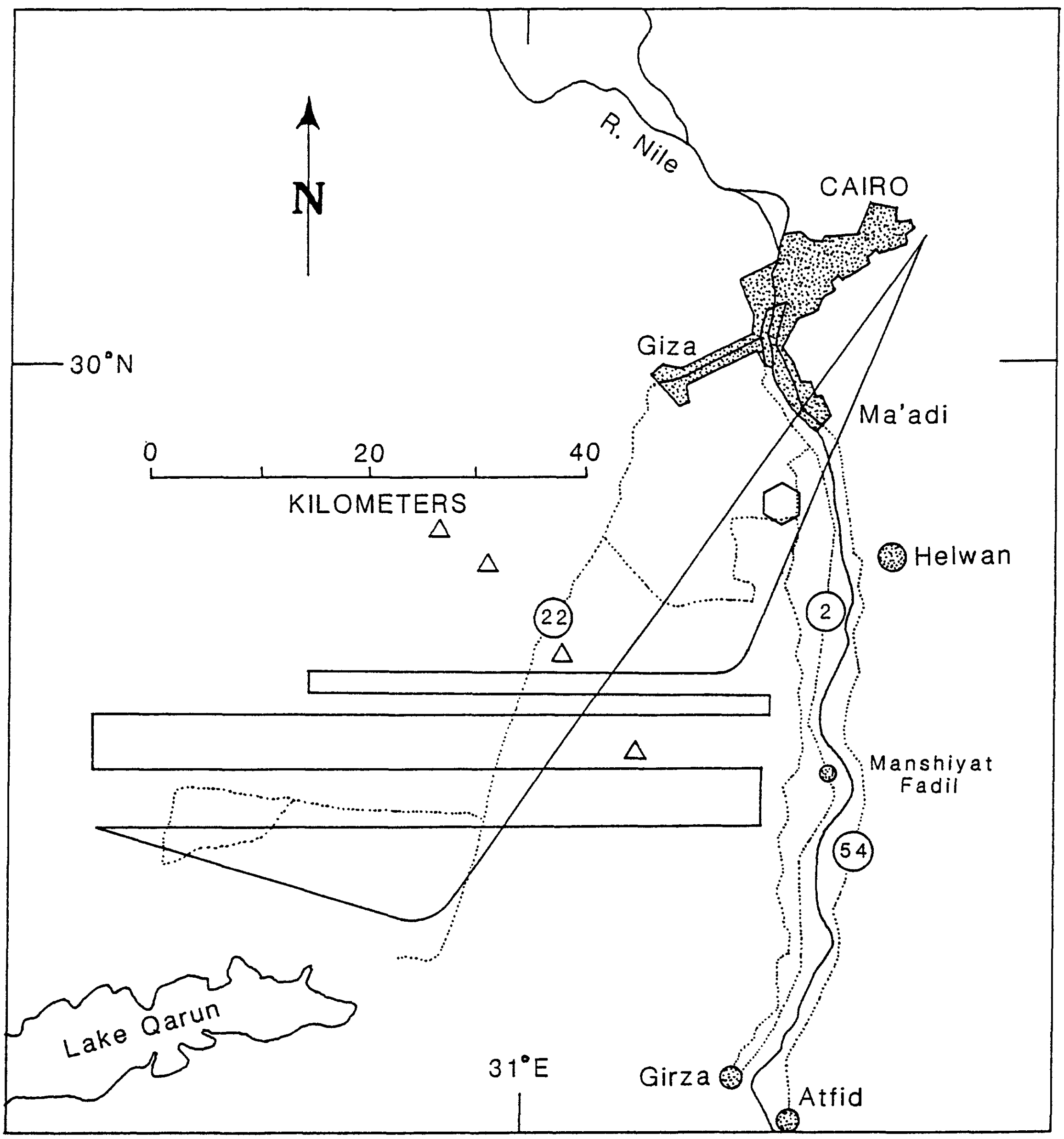


Figure 4. -- Map showing epicenters and paths used in searching for surface faulting. Main shock epicenter shown with hexagon, and early after shock epicenters by triangles. Solid lines show approximate flight paths, and dotted lines are ground traverses.

amount of movement) provided by Harvard University and based on early seismograph data from four reporting stations in other parts of the world (Massachusetts, Alaska, Norway, and Japan). Although focal mechanisms in general are ambiguous in that they identify two possible fault orientations, the known faults near Cairo that had been previously identified and mapped by geologists of the Geological Survey of Egypt allowed us to select a northwest-striking fault plane as being the more probable. The alternative fault plane, directed nearly north-south, does not match the local geology well although it does match the damage distribution of the earthquake (Figure 2). As noted in the previous section, however, the northerly trend in the distribution of damage is biased by population concentration along the Nile River. Figure 5, diagrammatically shows the configuration of the preferred fault plane with respect to the local geographic features. Attention is drawn to the direction of the fault plane's downward inclination -- northeastward toward Cairo. The combined epicentral location and northeastward inclination may have played an important role in distributing the strongest shaking to the southwest, away from Cairo -- thus helping to spare the city from the maximum shaking effects.

A reasonably accurate epicentral location, a well-constrained focal mechanism, and known surface geology will establish the identity of the fault responsible for the generation of an earthquake. In the Dahshur earthquake, however, no evidence in the epicentral region of either a new fault rupture or of previous fault ruptures at the appropriate location and of the proper orientation is known. Thus, we cannot follow the usual procedure of assigning the crustal movement to a known specific fault which, if geographically extensive, customarily bears a name (such as the San Andreas fault in California). Not only is the active fault in this earthquake unnamed, we cannot unreservedly confirm that this particular fault has ever in the past broken through to the ground surface where its existence could be established by geologic mapping. As stated previously, however, many preexisting faults have been recognized in the greater Cairo area, particularly east of the Nile. These will be discussed later in this report.

In consideration of the available seismological evidence, the absence of faulting on the ground surface is not surprising. By combining the NEIS focal depth (about 25 km) with several parameters of the fault motion established with the Harvard moment tensor solution, the radius of the subsurface rupture patch is estimated to be about 2.6 km, or roughly 10 percent of the focal depth. Although the rupture patch is probably not exactly circular in shape, the great discrepancy between this radius and the distance up the fault to the ground surface (about 30 km) rules out the likelihood of surface rupture. Even in California where earthquakes commonly occur at 5-10 km depths, surface rupture is rare for events of this magnitude.

The details of the likely relative fault motion at the focal depth of the earthquake are as follows, all derived from the Harvard focal mechanism: in map view, the northeastern side (the Cairo side) of the fault moved about 0.9 m in a nearly eastward direction (N 84^{o} E) with respect to the opposing side; vertically, the Cairo side moved relatively downward about 0.9 m. However, because of the way the observable components of displacement diminish with distance from the dislocation source, changes in horizontal position and vertical elevation at the ground surface would be nearly imperceptible at the epicenter, directly over the rupture patch. Only the highest precision surveying techniques performed before and after the fault movement could detect such small changes on the ground surface, if they are present at all. Even if such surveying had been done, independent geodetic confirmation of the subsurface fault displacement probably is impossible because the uncertainty associated with these surveying techniques would exceed the expected changes on the ground surface.

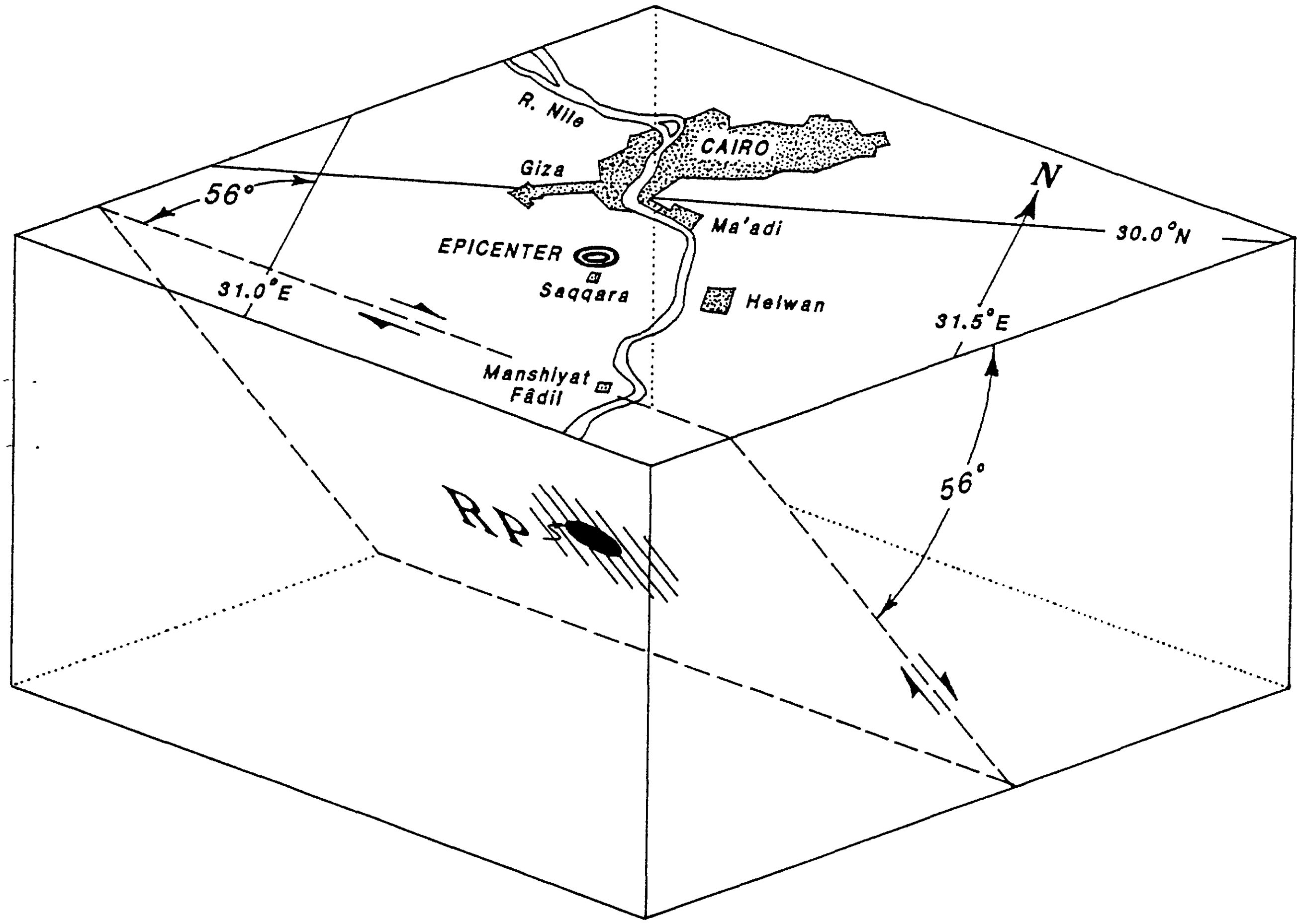


Figure 5. -- A transparent earth model of the Cairo region for the 12 October 1992 earthquake. The block is a 60.6 km square on the surface and 40 km deep. Intercepts of the plane of the activated fault are shown with dashed lines, but new rupture is confined to the black patch labelled "RP" (radius 2.6 km); down-dip parallel rulings show unbroken parts of the fault plane around the rupture patch. Arrow pairs show relative horizontal and vertical sense of motion at the rupture patch. Adapted from data of NEIS and G. Ekstrom and M. Salganik of Harvard University.

Previously in this section, we pointed out that the areas most strongly shaken in this earthquake lie to the south of the greater Cairo area. Such a distribution of strong shaking is consistent with a northeastward inclination of the activated fault, which in turn agrees with the position of the mainshock epicenter relative to the locations of more shallow aftershocks determined by the Geological Survey of Egypt and the National Research Institute of Astronomy and Geophysics at Helwan to lie farther southwest. Both the effects of "directivity" (enhancement of shaking intensity in the direction of rupture propagation along the activated fault surface) and the radiation pattern of shear waves (which are primarily responsible for causing damage) would also predict the strongest shaking south or southwest of the epicenter for a fault surface inclined northeastward at the angle given by the focal mechanism. The other shear-wave maximum, radiated normal to the likely fault plane, would have arrived at the ground surface northeast of Cairo with only about two-thirds of the intensity of the other maximum because of the effect of geometric spreading. The region between Ma'adi and central Cairo may have thus lain in an "island" between these two maxima in shear-wave intensity -- a fortunate happenstance for the city.

We should emphasize, however, that although the apparent match of the known geologic structure, the earthquake focal position, and the focal mechanism as presented here is attractive, the details and possibly some of the main features of this picture could change as additional data are eventually assembled and analyzed. As an example, a preliminary focal mechanism by NEIS based on the polarity of first motions at some of the WWSSN stations does not agree well with the Harvard solution. We have favored the Harvard solution herein because the moment-tensor method extracts important information about the event from each seismographic record in its entirety, not just initial polarity, and thus it represents a better average picture of the rupture process. At present, the NEIS first motion focal mechanism has many internal inconsistencies that might be resolved at some future time.

The distribution of earthquakes in the Nile delta region attests to the likelihood that numerous faults exist there. We have already mentioned that , in the greater Cairo area, numerous preexisting faults have been recognized by the Geological Survey of Egypt. These are illustrated in Figure 6. The depiction of the family of northwest-trending faults in Figure 6 shows what is probably a minimum number of such faults because some likely lie beneath the city where they cannot be recognized on the land surface. If they are subject to reactivation, as was the fault responsible for the Dahshur earthquake, collectively they pose a potential hazard to the city. If any of them ruptured at shallow crustal depth and were accompanied by fault displacement at the ground surface, the effects could be far worse than those experienced in the recent earthquake, even if the magnitude was similar.

<u>Secondary Geological Effects of the Earthquake</u>

Three kinds of geologic effects related to earthquake ground shaking may occur in earthquakes the size of the Dahshur earthquake and larger. These geologic effects are landsliding, non-fault ground fracturing, and liquefaction. In the Dahshur earthquake, we observed only minor examples of the latter two in our field investigations.

Ground fractures: As briefly mentioned earlier, fractures were found on the ground surface on the north side of Lake Qarun in the Faiyum depression. These extensional fractures showed at most only a few centimeters of opening along preexisting planes of weakness in rock materials. Some

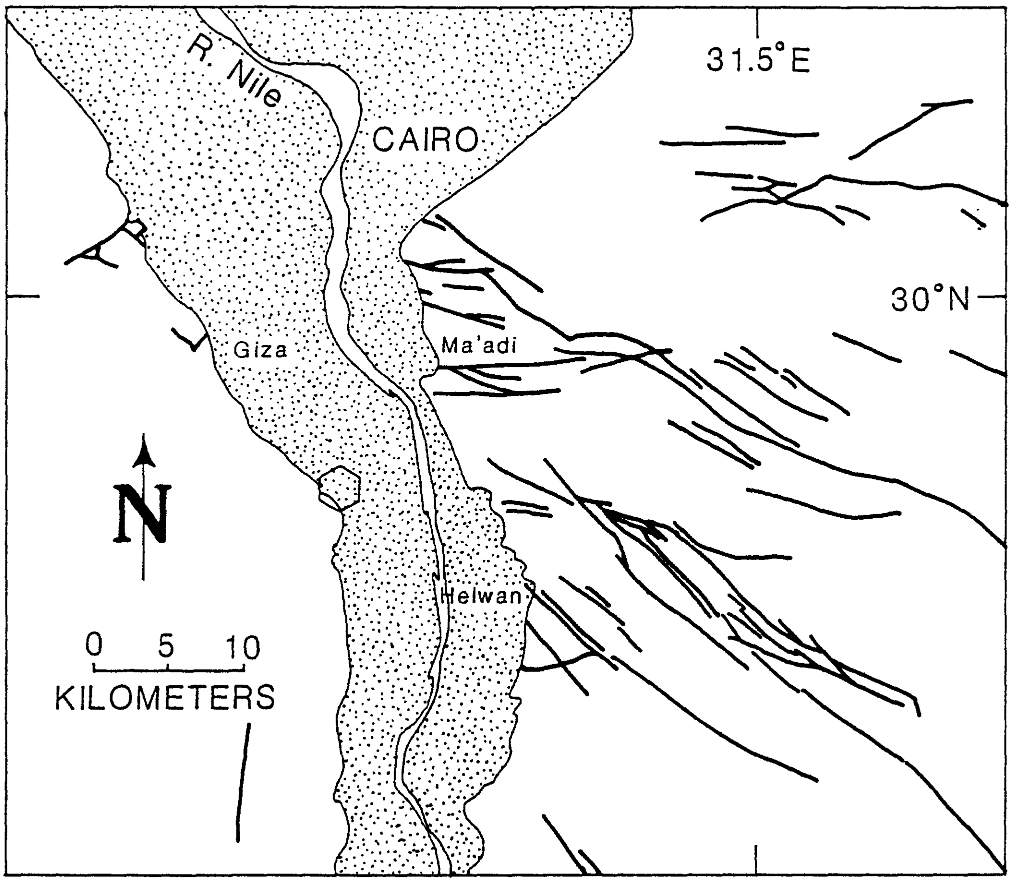


Figure 6. -- Mapped faults in the greater Cairo area, shown by heavy lines. NEIS epicenter shown by hexagon. Flood plain deposits of the River Nile (dotted Pattern) and urbanization conceal the northward continuation of the faults. Adapted from mapping by the Geological Survey of Egypt.

of the fractures developed along joint planes in rock near steep bluffs, and they are easily explained by the combined effects of the shaking and lack of lateral confinement at the faces of the bluffs.

A second kind of minor ground fracturing developed locally in the same area in old lake sediments near the present Lake Qarun. The fracturing occurred along the boundaries of desiccation polygons that originally formed in drying mud as an ancient lake shrank to the smaller size of the present Lake Qarun. Each of these polygons is only a few meters in size, and the scattered new fractures appeared to follow the preexisting boundaries exactly. The polygons appeared to have jostled independently of one another when strongly shaken and their final resting positions did not match the original ones precisely.

Liquefaction: The silty to fine-sandy soil that makes up the floodplain of the Nile is a material that is is ideally suited to the phenomenon known as liquefaction, when it is water-saturated and strongly shaken. With prolonged shaking, soil of this composition can quickly convert from a solid material into a liquid which has no strength to support structures that may rest on its surface. Although the potential for widespread liquefaction is very high on the Nile floodplain, and especially so in irrigated fields, in our field search we found only one example.

We visited the site of reported sinking of Highway 2 west of the Nile near the village of Manshiyat Fadil and discovered that the field east of the road had liquefied over a small area, probably only a few acres in extent. Because this was observed directly adjacent to the pavement which had reportedly sunk as much as 1.5 m, we present this account of what probably happened there.

The roadbed at that location is built up as a causeway standing about 3-4 m above the level of the adjacent agricultural land. We surmise that the zone of liquefaction, revealed on the ground by sand-boils, actually extended under the roadbed. When the strength of the soil beneath the roadbed vanished during the earthquake, the causeway sank as the liquefied soil escaped laterally into the field.

Ground Motion and Seismological Instrumentation

The opportunity to capture recorded data from the Dahshur earthquake was lost primarily because of three reasons: (1) lack of strong motion instrumentation (accelerographs), (2) inadequate geographic coverage of instrumentation networks presently installed and (3) inadequate dynamic range of the seismographic instrumentation in place.

There are no strong motion accelerographs installed in metropolitan Cairo. Twelve accelerographs are installed in Aswan for safety considerations related to the Aswan dam. However, none of these instruments were triggered by the earthquake that was moderate in size and located about 500 km to the north. A strong-motion recording network in and around the Cairo metropolitan area needs to be established using both free-field instrumentation and building instrumentation. Buildings for instrumentation should be carefully selected to assure the broadest applicability of the data to numerous high-occupancy buildings of similar construction. Free-field stations should be carefully selected to sample ground motions in the predominant soil types and thicknesses throughout the city. Pockets of building damage observed in south Cairo might be related to site effects, such as ground-motion amplification within the soil column at these specific locations. Instrumental recordings could identify such areas of possible increased hazard and quantify the amount of amplification above the average background ground-motion level. Lacking such recordings, there is always the question of whether anomalously located pockets of damage are due to deficient engineering, deficient construction practices, or an actual physical enhancement of the ground-motions. Over the past decade, ground-motion amplification has been recognized as the primary cause of anomalous, severe damage in earthquake areas and a primary cause of fatalities in the 1985 Mexico earthquake, that devastated high-rise construction in Mexico City, and in the 1989 Loma Prieta, California earthquake, in which the elevated portion of the I-880 freeway collapsed in the city of Oakland.

Figure 7 shows station locations of the Egyptian Seismograph Network. A telemetered digital network is in place at the Aswan dam. The remaining network has a very linear north-south distribution of stations (probably due to the ease of accessibility as well as limited equipment) that is not conducive to high-quality epicentral locations. This network should be augmented with additional stations for better coverage of the Cairo metropolitan area and the populated Nile valley, including the El Faiyum area. The overall dynamic range of the network needs to be increased so that seismological data from important earthquakes, as the Dahshur earthquake, is not lost from instrumental "clipping" of the seismograph records. There are a variety of ways of doing this, each having its own set of considerations. New broad-band, digital recording seismographs have the highest dynamic range of any instruments. However, the reliability and mode of signal transmission, cost of sophisticated maintenance, and overall system reliability needs to be considered before commitments are made to these state-of-the-art systems. More appropriate, perhaps, would be augmenting the existing network with newer models of analog seismographs that are easily maintained, reliable, and can be used efficiently with a variety of types of data transmission ranging from telephone lines to satellite telemetry. With a properly planned network of such stations, a variety of dynamic ranges can be sampled by different instruments thereby simulating the broad-band data collection of sophisticated digital networks.

At the very minimum, adequate supplies of repair parts and of test/calibration equipment needs to be assured so that the seismological instrumentation in place is maintained with a minimum amount of down-time.

Recommendations

1. The historic record of earthquakes in the region around Cairo, together with the 1992 earthquake occurrence, clearly indicates that future events of a similar kind or larger may be expected. The earthquake ground-motion hazard in Egypt, particularly northeastern Egypt and the Cairo vicinity, should be quantified in ground-motion hazard maps that are useful to modern earthquake-resistant design of structures, land-use planning and economic development. As part of this hazard map development, estimates of the frequency of earthquake occurrence in the region needs to be improved.

2. The vulnerability of common, high-occupancy construction types to earthquake ground motions in the Cairo metropolitan area needs to be established to identify potential retrofit solutions that minimize risk and for use in economic loss analyses.

3. Faults in the Cairo region should be studied specifically to determine, if possible, how much time has elapsed since they last moved. This is usually done in earthquake-prone areas by determining the age of the oldest sediments that cover the faults and have not yet been

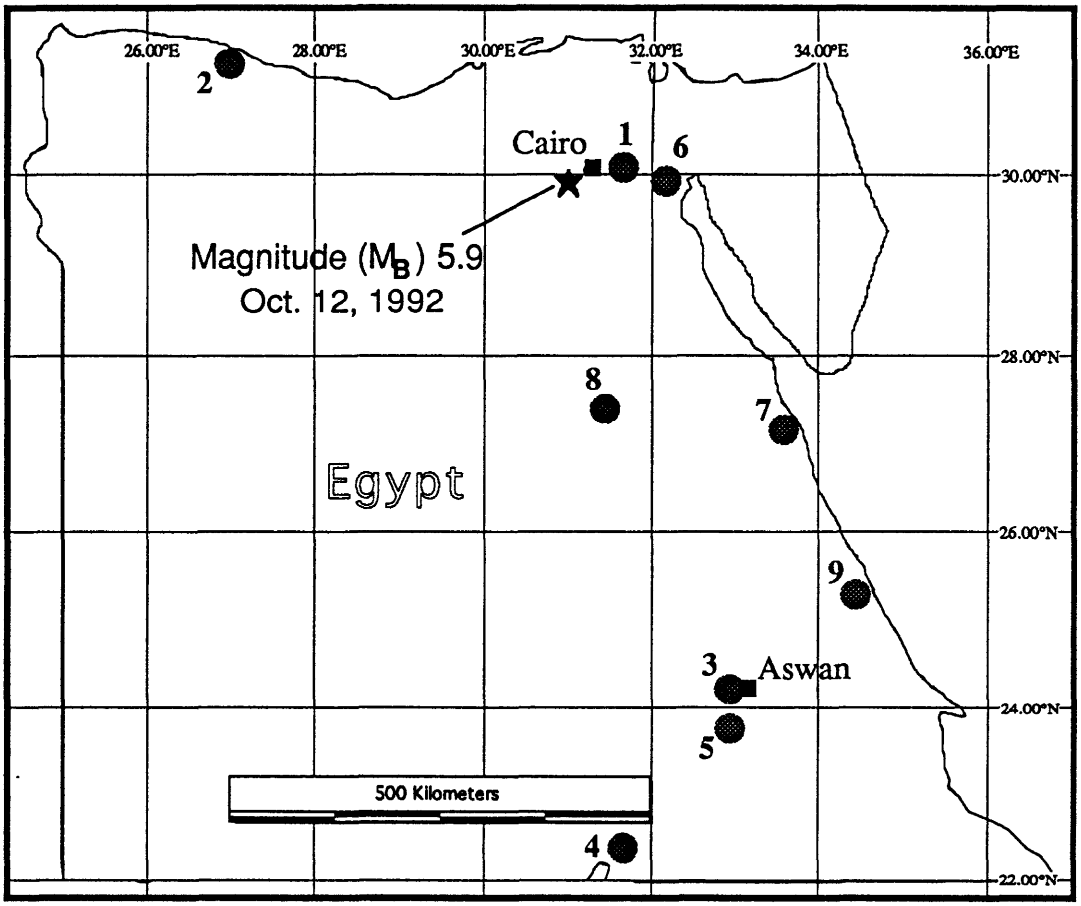


Figure 7. -- The Egyptian National Seismograph Network.

1 - HLW In operation since 1903 S.P and L.P WWSSN station since 1962.
2 - MMT S.P Soviet SMK seismograph, in operation since 1975.
3 - ASW S.P and L.P Soviet SMK seismograph, in operation since 1975.
4 - ASI S.P Soviet SMK seismograph, in operation since 1975.
5 - Aswan telemetered seismograph network, in operation since 1982.
6 - KOT Single vertical S.P seismograph in operation since 1986.
7 - HUR Single vertical S.P seismograph in operation since Aug. 1988.
8 - TAS Single vertical S.P seismograph in operation since Nov. 1989.
9 - MRA Single vertical S.P seismograph in operation since Jan. 1990.

displaced, or alternatively, by establishing the age of the youngest sediments that have been offset by the fault movement. Radiocarbon-dating is probably the most widely used technique of determining the age of sediments, and it can be applied to materials up to about 60 thousand years old. Determination of the activity of faults according to this simple convention might be useful to Egyptian authorities charged with public safety in the Cairo area.

4. There is a great need for assuring maintenance and providing spare parts for seismological instrumentation presently in place as the Egyptian Seismological Network. The nine-station network needs to augmented with more instruments in the vicinity of Cairo and the dynamic range of the network needs to be increased to ensure proper collection of the much needed seismological data.

5. A strong-ground motion recording network in and around the Cairo metropolitan area should be established using both free-field instrumentation and building instrumentation. Buildings for instrumentation should be carefully selected to assure the broadest applicability of the data to numerous high-occupancy buildings of similar construction. Free-field stations should be carefully selected to sample ground motions in the predominant soil types and thicknesses throughout the city.

V. OBSERVATIONS RELATED TO DAMAGE AND STRONG MOTIONS

The performance of building structures in Egypt during the earthquake can be best described by classifying them into two main groups: Buildings with little or no engineering input and buildings with various degrees of engineering input. These two categories will be discussed separately. Figures (photos) 1 through 29 for this section follow the text.

Buildings with Little or No Engineering Input

These can be classified into five categories:

1. Adobe buildings with "wood" roofs ("wood" here maybe thought of as date tree trunks, and most of the time unprocessed).

2. Brick masonry with "wood" roofs.

3. Brick masonry with reinforced concrete floors and/or roofs.

4. Stone masonry.with "wood" roofs.

5. Reinforced concrete frame with brick infill walls.

The building inventory did not include timber-reinforced adobe (or brick or stone) masonry structures. This is attributed to the scarcity of wood products. The damages inflicted on these types of buildings can be attributed to:

1. The walls are too thick without any tie-beams. In most damaged buildings, separation in the corner of the walls was observed.

2. The mortar in the walls is too thick with varying degrees of mortar quality.

3. The quality of brick is a varying parameter.

4. The wood used for roof is not properly anchored to the walls. In most cases, the roof timber does not extend over the total width of the wall. In most cases, the situation is adversely affected by the heavy loads on the roofs.

5. There is a very serious "false parapet" wall situation arising from the fact that on all buildings, the owners extend the walls in one way or another without any "out of plane" support.

6. The buildings are considerably stiff but their strength is not necessarily sufficient.

The deficiencies generally summarized above are exhibited in Figures 1 to 9. Figure 1 shows a brick-masonry (and partially stone masonry) building with corners separated. The construction lacks tie-beams and the second story side-wall is not integrated with the front wall. Figure 2 similarly shows a stone masonry building that has cracks. Both buildings have no tie-beams. Figure 3 exhibits the rubble from collapsed buildings and unprocessed palm tree trunks that are usually used as roof material. The fate of an adobe building is shown in Figure 4. The lack, or limited amount, of wood used is clearly exhibited in this figure. A better-built brick-masonry building is shown in Figure 5, again without tie-beams but at least the floor beams extending over the width of the walls. The figure also shows a reinforced concrete framed building with brick masonry infill walls. Both of these buildings performed well. Figure 6 shows a school building in (Girza) that experienced diagonal cracks and separation cracks of the infill walls (Figure 7). A view of the building from its back yard also shows the surrounding adobe buildings (Figure 8). The adobe buildings have heavy roofs with little or no timber except at floor levels. A corner column of the school building exhibits an inferior cold joint, deficient longitudinal rebar detailing and anchorage, and lack of shear reinforcement (Figure 9). The presence of walls in both directions of this wing of the school building may have prevented the collapse of this column.

Buildings with Various Degrees of Engineering Input

This category encompasses mid-rise and high-rise buildings in Cairo and vicinity and some lowrise (two to three stories) public and private buildings in the epicentral area. A number of buildings in Cairo suffered extensive damages and a few collapsed. The distress caused in engineered buildings during this earthquake appear mainly from random problems encompassing one or more of the following conditions:

1. Poor materials of construction (poor concrete quality, use of river based gravel, use of undeformed reinforcing bars, low-quality brick and/or mortar).

2. Poor detailing.

3. Overloading of the building columns to twice their design values (as possibly was in the case of the 14-story collapsed reinforced concrete building originally designed as 8

stories). The foundation footing to column reinforcement sticking out after rubble clearance appeared to be insufficient.

4. Structural system (use of spandrel beams or creation of short columns without appropriate shear reinforcement).

5. Cold joints improperly cast. This may be a larger problem in tall buildings during future earthquakes that may cause extensive vibration of the buildings.
6. Inferior joints of pre-cast construction at 10 Ramadan city.
7. Deficient foundation system (lack of piles in older buildings, possibly causing foundation rotation and therefore, tilting of the stiffer superstructure).

Prior to the Dahshur earthquake, there was no official earthquake-resistant design code. However, a "Draft Earthquake Resistant-Design Code" has been recently prepared. The implementation of this code should help to alert the designers to the new evolutionary design and detailing processes adopted in the code.

In general, most mid-rise and tall buildings are reinforced concrete framed with brick infill walls. Two such buildings under construction are shown in Figure 10. An older building of this type is shown in Figure 11. These buildings appeared to be well constructed and did not suffer any damage. Another building shown in Figure 12 appeared to be slightly out of plumb. The corner column (Figure 13) and some of the internal infill walls of the building were damaged. Similarly, the building in Figure 14 experienced damage to some of its columns and beams (Figure 15). These appeared to be local. The foundations of both of the buildings (Figure 12 and 14) possibly were not deeply embedded. The basement of the building in Figure 14 was only half embedded and one of the foundation footings (dug out) was not deeper than one-half meter and was moist because of high water table. To further illustrate possible foundation and foundation-embedment problems that may affect the performance of many such buildings in Cairo, in Figure 16, the foundation of a 14-story reinforced concrete building originally designed as 8 stories) is shown. The foundation footing to column reinforcement, sticking out after the rubble had been cleared, appeared to be insufficient. Clearly, such a foundation system is inadequate for an 8- or 14-story building. The collapse of this building resulted in the loss of 69 lives. There is a large inventory of such buildings in Cairo. It is possible that, in many cases, there may have been significant rocking of such 5-15 story rather stiff buildings that have shallow-embedded or non-embedded foundations.

The current inventory of tall engineered buildings appear to have had design input from collaborative and/or partner non-Egyptian companies having seismic-design experience. A general view of the area of the Nile River in Cairo and surrounding tall buildings is shown in Figure 17. There is a substantial number of reinforced concrete buildings with core shear walls and lift slabs constructed with fly-form technique (Figure 18). The core of one of these buildings under construction is shown in Figure 19. A few ductile moment-resisting framed reinforced concrete (Figure 20) and concentrically braced steel-framed buildings exist. In addition, there are several precast/prestressed buildings and buildings constructed with "tunnel forms." A prestressed/precast garage and office building shown in Figure 21 suffered minor damage. However, the great majority of these buildings performed well during this earthquake (M_S=5.2 and epicenter at approximately 18 km from Cairo). Many of the tall buildings are reinforced concrete framed with well-built infill walls of brick or cinder block masonry. Some of the tall buildings reach 40-50 stories.

A modern hospital building in Cairo is seen in Figure 22. This building was reported not to have suffered any damage. An older hospital (Figure 23) suffered minor structural and non-structural damage. One person was reported to have been killed and 400 persons injured in this hospital

Due to rapid increase of the population of Cairo because of migration from rural areas of Egypt, several satellite towns (aimed at having populations of half-million) are under construction and partially functioning. One such town is the "10th Ramadan City", located approximately 60 km north-east of Cairo. There is a large inventory of new buildings in this growing town (reinforced concrete framed buildings with infill walls, reinforced concrete tunnel-formed shear wall buildings and precast buildings). Figure 24 shows a reinforced concrete building with infill walls (some completed and another under construction). The reinforcement, both longitudinal and shear, is clearly deficient. Some of the precast-panel shear-wall buildings are shown in Figure 25. Some of these buildings suffered damage (Figure 26). Their vulnerability during larger (and/or closer source) earthquakes is an open question. Of considerable concern is the significant number of precast framed construction that is under way. The lack of quality control of materials and construction (*e.g.*, the lack of proper connections) can be a source of poor performance during future events. Figure 27 illustrates these buildings under construction. Figure 28 shows the close-up of the frame joints. Figure 29 shows the precast beams with very minimal reinforcement (and no reinforcement around the ends).

Strong-Motions Not Recorded

The existing 11 strong-motion accelerographs in Egypt, deployed at approximately 500 km from the epicenter as part of the Aswan Dam project, did not trigger and therefore did not record the earthquake. There were no strong-motion accelerographs in Metropolitan Cairo or its vicinity.

Recommendations

1. Acquisition of strong-motion data for engineering use is a necessity. It was a great misfortune that no strong-motion records were obtained during the October 12, 1992, earthquake. Therefore, it is imperative that a much more extensive strong-motion array be deployed within and around Metropolitan Cairo (and other seismically active regions of Egypt). The purpose of such an array is to record site-specific motions during future earthquake and facilitate the assessment of the attenuation characteristics of the Egyptian earthquakes and amplification and other specific site conditions of Cairo Metropolitan for engineering use. It is not illogical to assume that significant amplification of earthquake motions may occur in the alluvial environment of Cairo and vicinity. The long period characteristics of the amplified motions of deep alluvial site conditions must be recognized for use in design of future construction as well as assessment of earthquake risk of the tall building inventory in Cairo.

2. Faculty members and graduate students of Egyptian universities should be involved in earthquake reconnaissance, recovery, and rebuilding (both retrofit and repair) efforts. At present, the degree of dialogue between the academic community and the central and local

governmental offices is unknown. Faculty members who have recently returned to Egypt after having completed their graduate studies, being equipped with state-of-the art technologies in earthquake engineering, must be encouraged to take active roles and interact with the central and local governmental agencies.

3. Courses in earthquake engineering related subjects should be further emphasized in the university engineering school curricula.

4. It is clear that earthquake preparedness issues, including clear procedures for emergency response and relief efforts, must be addressed. Drills can be organized to train both public officials and the public.

5. Since earthquakes in the future may cause more severe shaking and possibly more extensive damage than that during the 12 October 1992 event, ways must be found to assess the risk to buildings in Cairo. Again, I suggest an influential task force consisting of knowledgeable faculty members, practicing engineers, seismologists and geologists be formed to address this issue and search for ways to define policy.

6. For engineered buildings, most of the observed damage was due to detailing and/or poor quality control. Commonly-known errors made during design and construction of earthquake resistant structures should be avoided. In summary these include:

    a. Short column and spandrel beams. The designer should avoid these or should provide proper detailing.

    b. Proper detailing of beam-to column joints and immediate regions around the joints.

    c. Quality control of materials and construction.

    d. Extra precaution must be taken in the case of precast and pre-stressed construction because of the delicate nature of their joints.

7. For non-engineered buildings, the construction practices must be thought of in terms of the resources of the people and their needs. Naturally, the farmers will want to be near their land. Therefore, the following recommendations are appropriate:

    a. Provide guidance and education to the rural people. Provide simple and understandable posters showing "what to do?" and "what not to do", "how to do?" and "where to do." These posters can demonstrate the dangers caused by "parapets" or show how to mix concrete or the mortar for masonry.

    b. In cases where certain materials of construction are in short supply (such as timber), these materials could be supplied by the government at nominal cost. For example, in rural construction, use of tie-beams using timber will be very helpful in securing the safety of many rural construction.

    c. Low-cost pre-fabricated and/or properly designed precast buildings can be made available.

d. Retrofit and strengthening of rural homes can be achieved by simple methods. But these methods must be communicated to the rural people. For those reinforced concrete buildings with infill walls, strengthening can be achieved by well-known methods such as:

   i. Capping of columns.

   ii. Addition of reinforced concrete shear walls.

   iii. Epoxy repair.

   Although most of the inventory of one- or two-story reinforced concrete framed buildings (with infill walls) in the epicentral area performed well, in future construction,

   i. Detailing can be improved.

   ii. Anchorage lengths can be improved.

   iii. Quality of materials and construction can be improved.

8. Although not explored in detail, Cairo has a serious high-water-table problem because of the steady level of Nile River. Due to capillary action caused by the high water table, the foundation systems deteriorate. This has been a major problem, particularly to the historical Islamic Buildings and Mosques. It was also noticed in the foundations of a few buildings in Cairo.

VI. BRIDGE/BARRAGE SURVEY

The main thrust of the Earthquake Engineering Research Institute (EERI) team was on inspection of failed and damaged buildings. Inspection of the bridges (by boat) was carried out by the EERI team on 21 October, 1992, prior to van de Pol's arrival. Therefore, separate inspections were made, generally on foot, and on 30 October by rented boat of all bridges across the Nile, as well as many under and overpasses of highways and streets in greater Cairo. These inspections confirmed that none of those structures were damaged by the Dahshur earthquake. These inspections included evaluation of potential damage in case of an earthquake in the future of greater magnitude, and longer duration. The inspections did not reveal any external damage. Inspections included searches for the following types of damage: 1) Damage of and around supports, 2) cracks, fractures and exposure of reinforcing steel in piers, columns and beams, 3) Damage to the foundation, and for overpasses footings, 4) separation of structural segments, due to shaking by the earthquake.

Damage of or Around Supports

No damage was detected on any of the supports of the structures inspected. If damaged, the following types of damages could have been expected:

a. Cracking or deterioration of mortar under support.

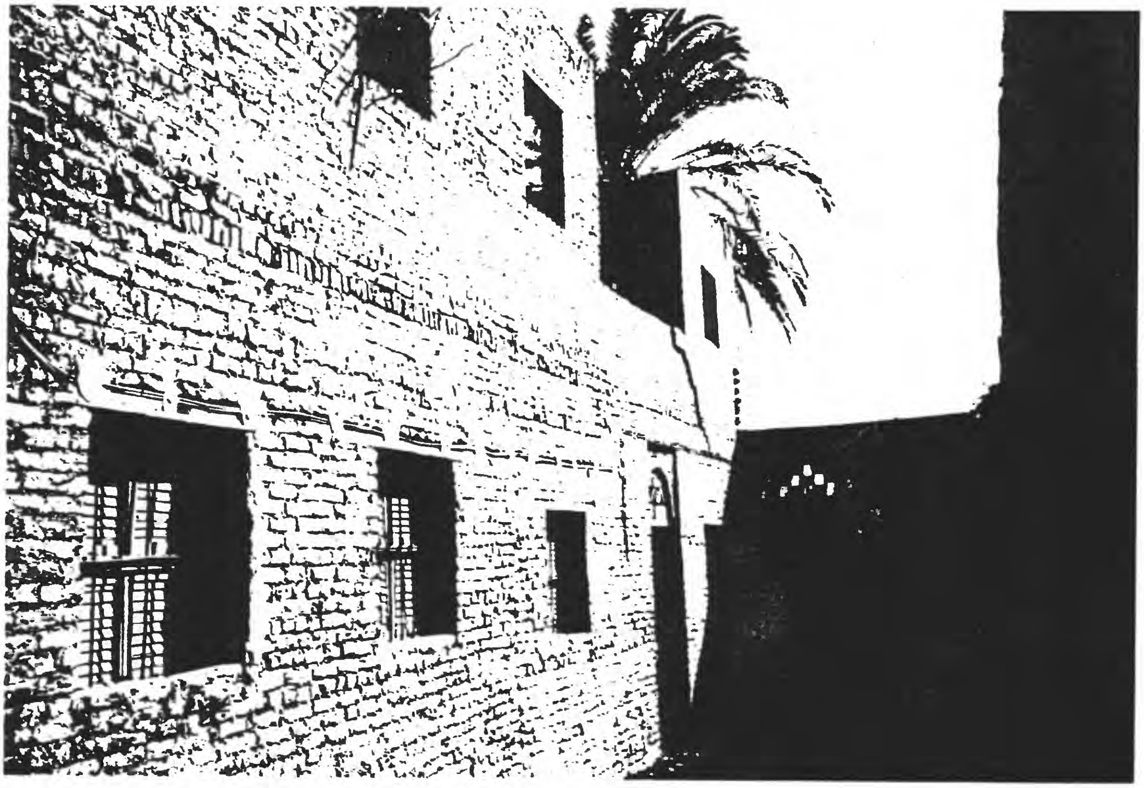


Figure 1. A brick masonry building without timber reinforcement or tie-beams.

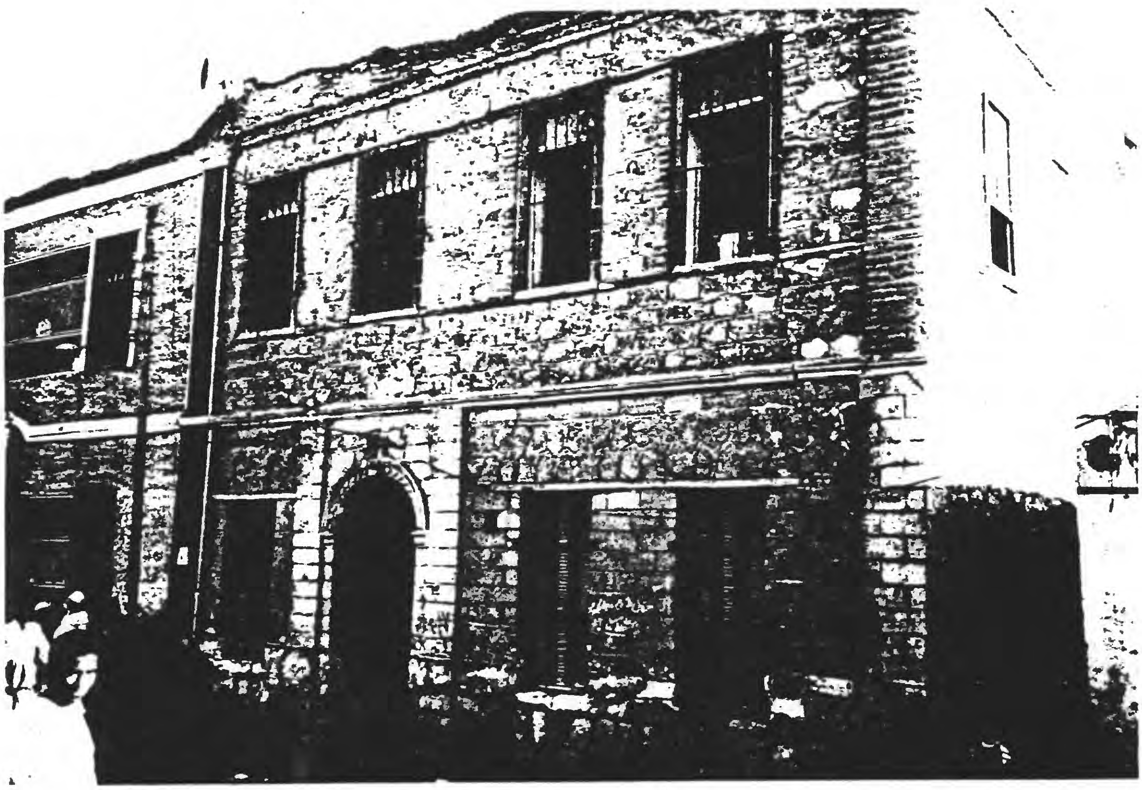


Figure 2. Separation at the corner of stone masonry building.

Figure 3. Rubble of collapsed adobe buildings and unprocessed palm tree trunks.

Figure 4. Collapsed adobe building surrounded by those standing up.

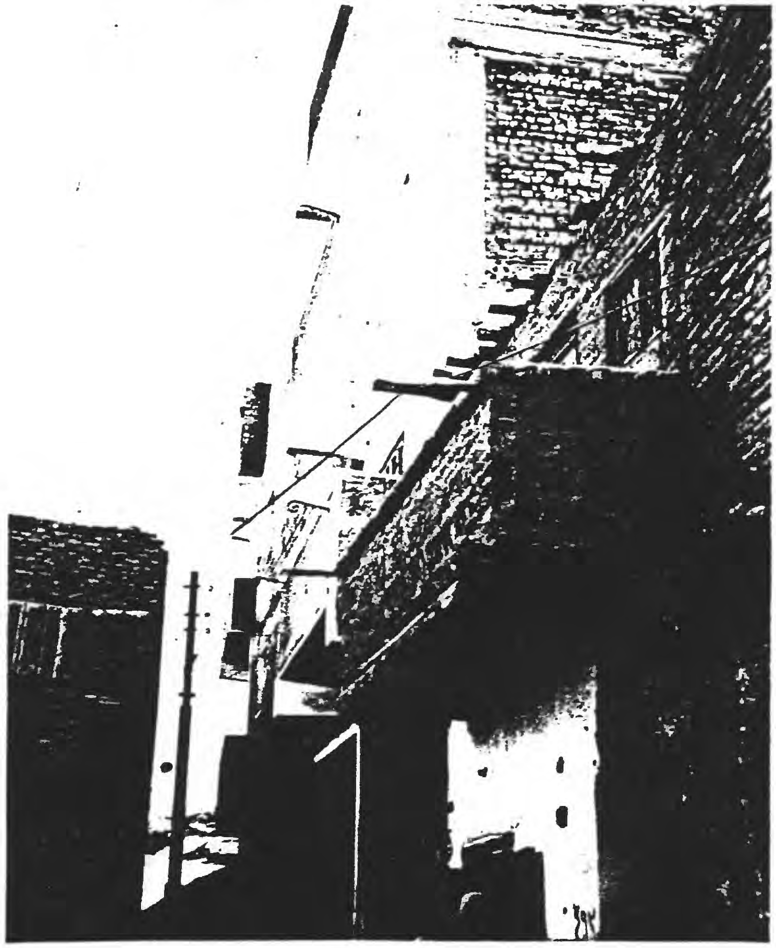


Figure 5. Better built brick masonry and reinforced concrete framed building with infill walls.

Figure 6. School Building (Girza).

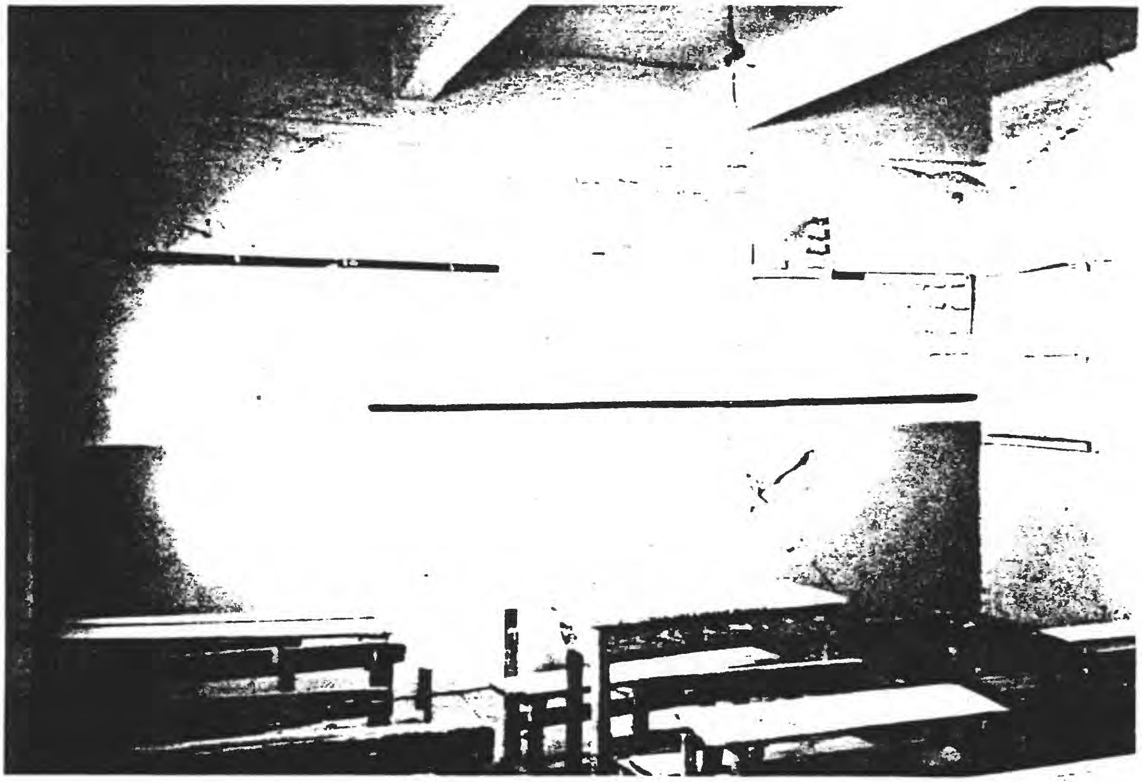


Figure 7. Diagonal cracks and separation of infill walls.

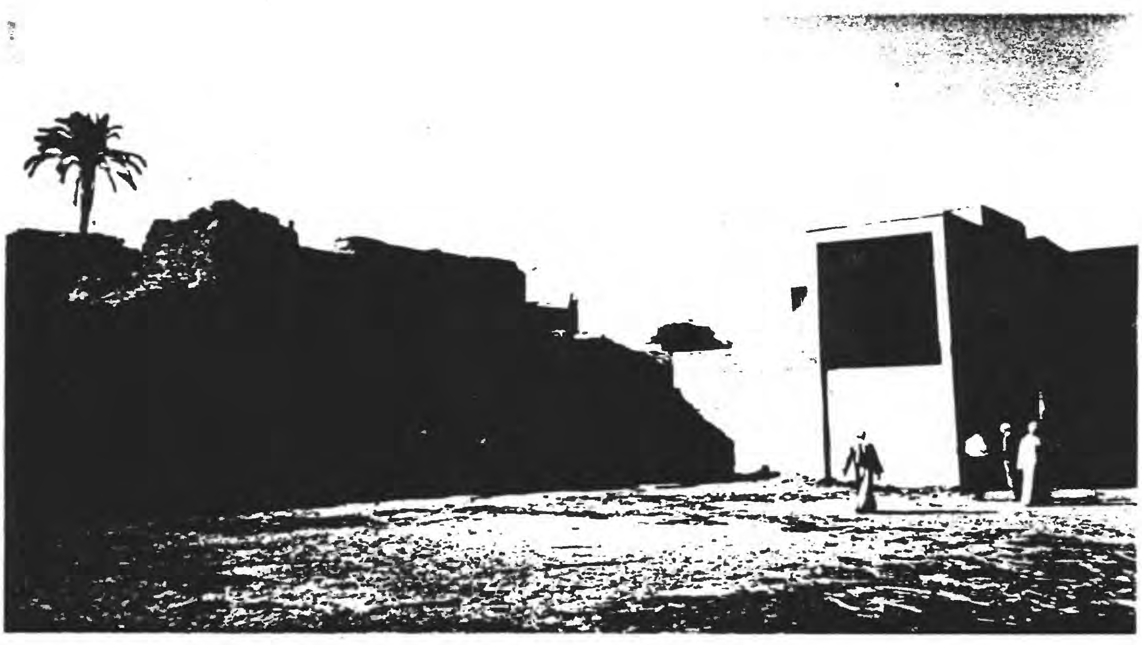


Figure 8. A view of the school building from its back yard.

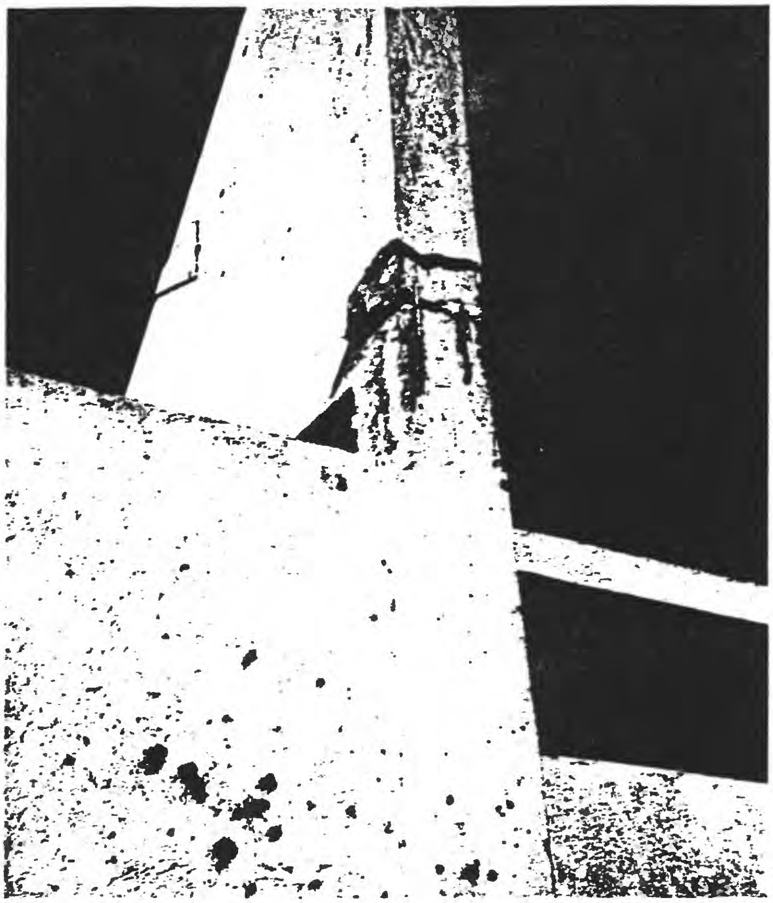


Figure 9. Cold jointed and deficiently detailed corner column.

Figure 10. Two reinforced concrete framed buildings with infill walls (under construction).

Figure 11. An older reinforced concrete framed building with infill walls.

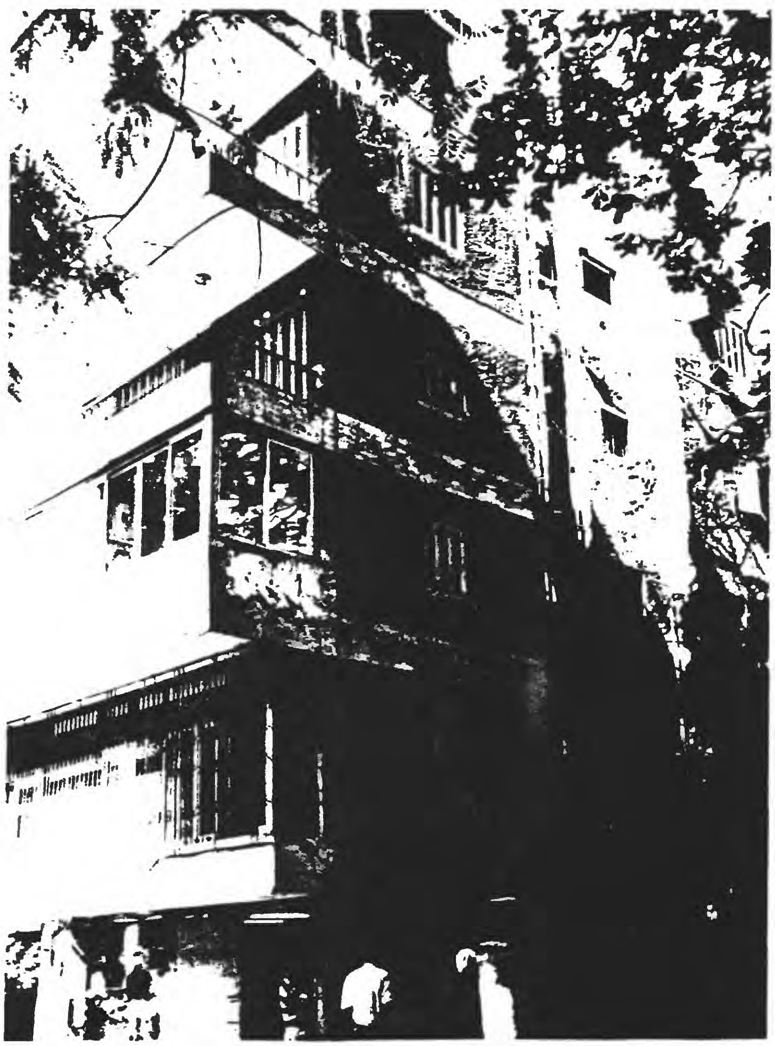


Figure 12. A six-story reinforced concrete framed building with infill walls.

Figure 13. Damaged corner column of soft-story entrance level of the six-story building.

Figure 14. An eleven-story reinforced concrete building with infill walls.

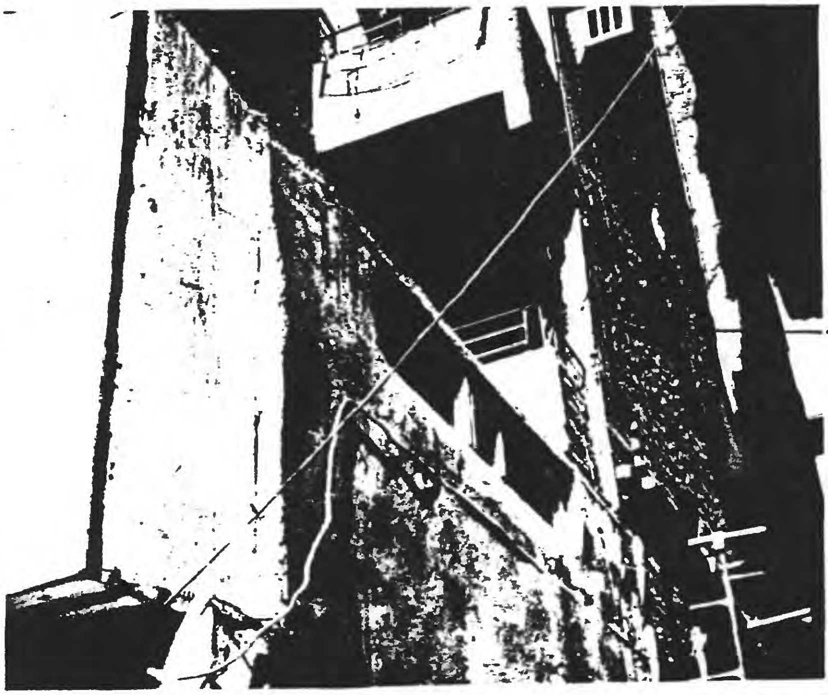


Figure 15. Damaged column (already cosmetically repaired).

Figure 16. Foundation of the eight (later modified to fourteen) story building that collapsed.

Figure 17. General view of Cairo Nile River and surrounding tall buildings.

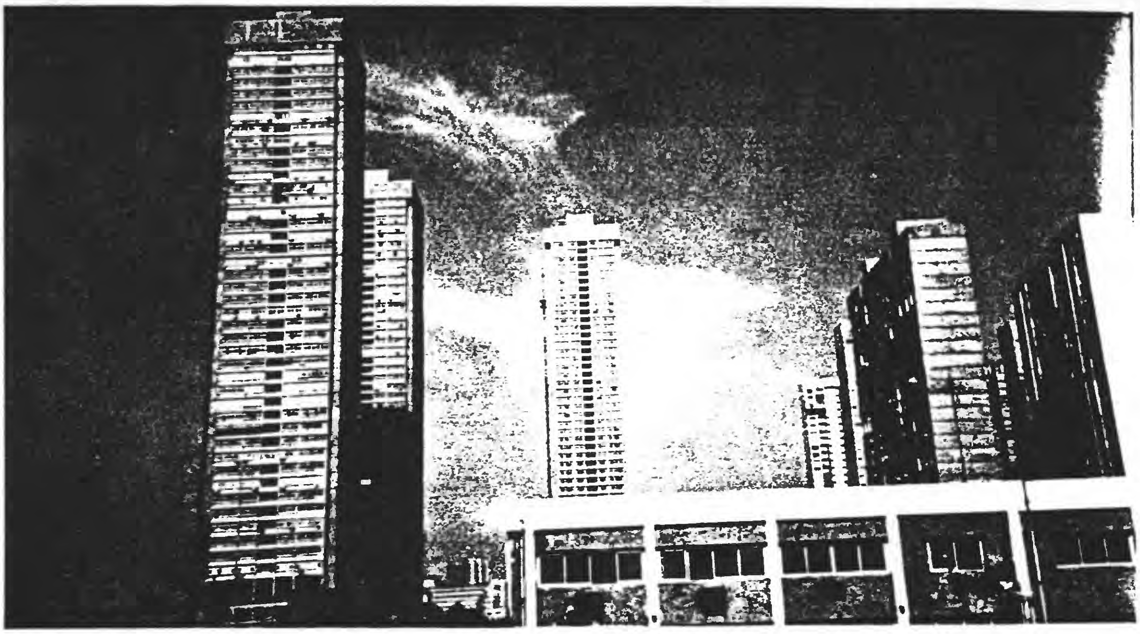


Figure 18. Tall buildings constructed with core shear walls.

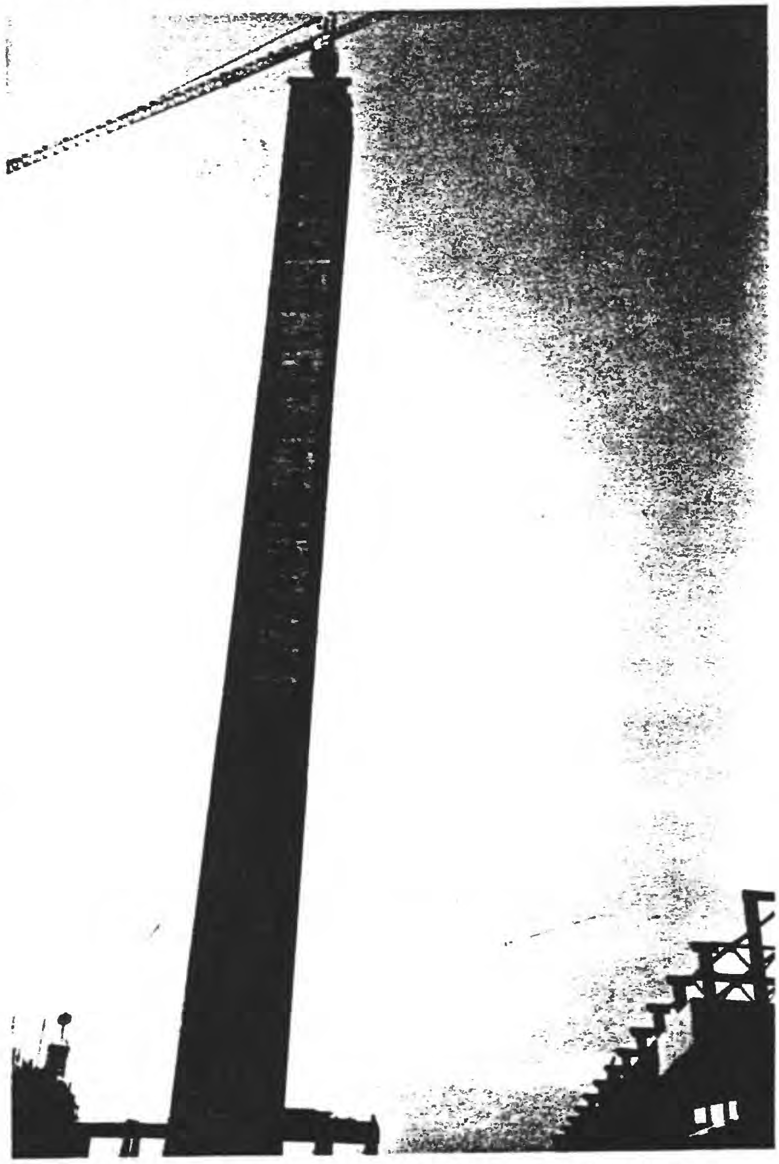


Figure 19. Core shear wall under construction.

Figure 20. Ductile moment-resisting framed reinforced concrete building.

Figure 21. Precast and pre-stressed garage and office building.

Figure 22. Nasser Institute Hospital in Cairo.

Figure 23. Shobra Hospital in Cairo.

Figure 24. "10 Ramadan City" -- Reinforced concrete framed buildings with infill walls (complete and under construction).

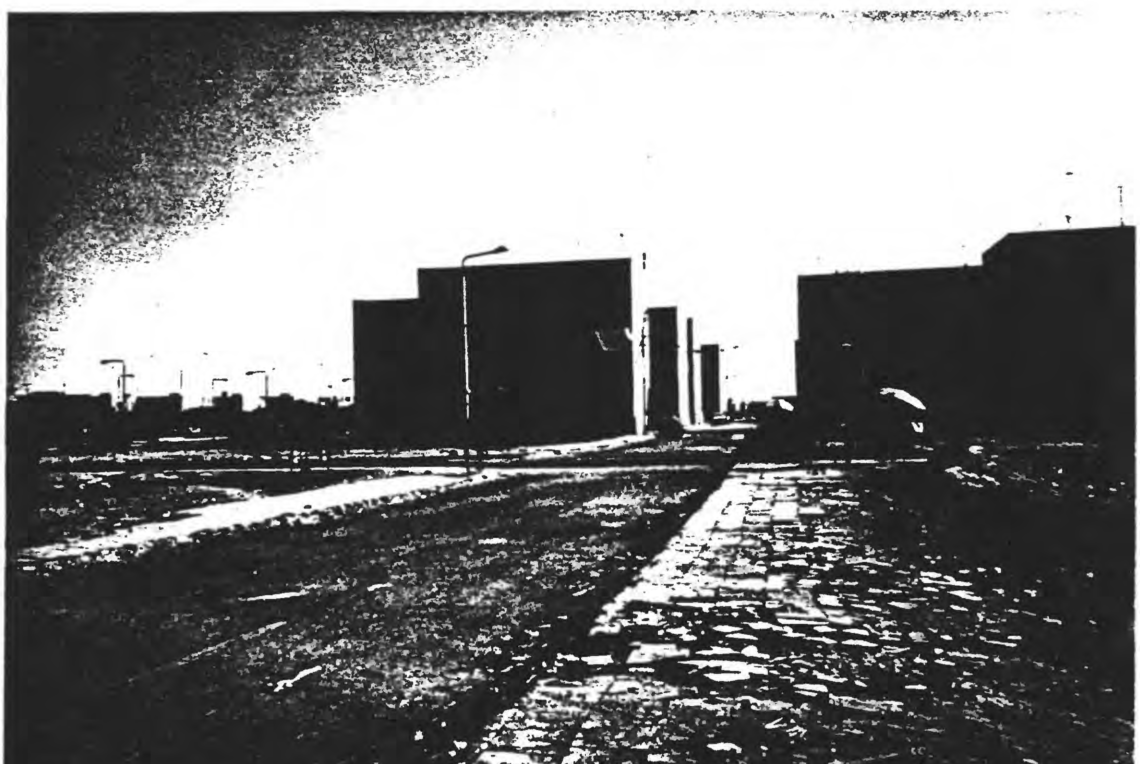


Figure 25. "10 Ramadan City" -- Precast panel shear wall construction.

Figure 26. "10 Ramadan City" -- Separation of panels at corners.

Figure 27. "10 Ramadan City" -- Precast construction.

Figure 28. "10 Ramadan City" -- Precast construction.

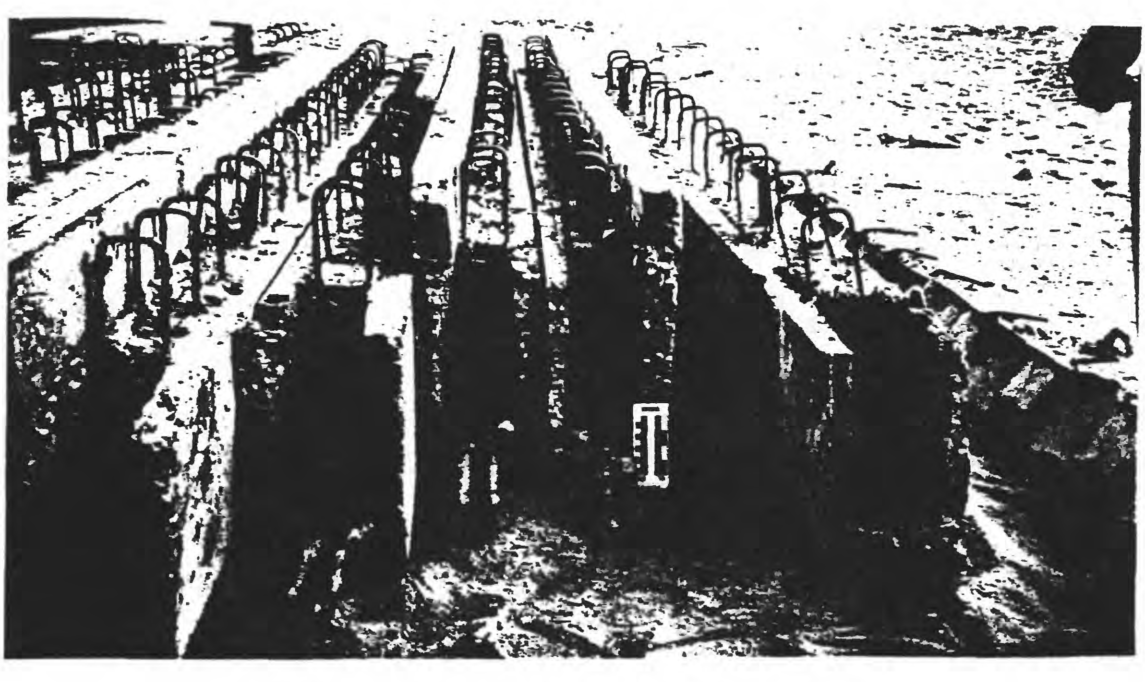


Figure 29. "10 Ramadan City" -- Precast beams.

b. Fracture of sliding or rolling support.

c. Corrosion of metal parts, such as pins, in a movable bearing.

Most of the above listed types of damage, if found, would be unrelated to earthquake induced forces, yet could contribute to failure as a result of a major seismic shock.

Cracking of Concrete in Piers and Column Supports

Fortunately the earthquake did not damage any of the piers and columns inspected. Most overpasses in Cairo are supported on reinforced rectangular columns; reinforced concrete Tee-shaped supports and structural steel Tee-shaped supports. Bridges across the River Nile are supported on concrete or masonry caisson type piers.

Even though no damage is evident, nevertheless, reinforced concrete columns and supports of whatever shape should be checked for the thickness of cover on reinforcing steel. Quality control in placing steel, and assuring that cover is neither less nor more than called for in the design, appears to be less than desirable. If the cover on the reinforcing steel is more than called for in the approved design documents, the "d" or effective depth used in calculating the quantity of reinforcing steel required, would be less than the design value, and recalculation would show that the steel as installed is less than the reduced "d" would dictate. Thus the structure could be endangered if ever subjected to the full design loading. On the other hand, if the cover on the reinforcing steel is less than required, the steel could be exposed to moisture, causing rust, and spalling off of concrete, in addition to potential weakening of the supports due to loss of bond between steel and concrete. To determine concrete cover on the reinforcing steel as constructed, the depth of concrete to the reinforcing steel should be determined on those structures located in routes essential to disaster mitigation through proper access by emergency vehicles, such as fire trucks and ambulances.

Steel supports were checked for corrosion and deformation, none of which was detected.

Damage to foundations and overpass footings

Detection of damage to foundations, in particular for piers in water, cannot readily be determined through visual observation. To assure that no settlement occurred, a level-survey is recommended. Comparison of elevations for the structure as constructed, with elevations measured after the earthquake, would identify those foundations which settled as a result of the quake. If the settlement is found to be large, and could result in failure, soil borings adjacent to the supports, followed by stabilization with pressure grouting or a similar method would be required. Repair should be designed on an individual basis, depending on the severity of the settlement.

Separation of structural segments due to earthquake shaking

Fortunately no damage was sustained by bridges or overpasses as a result of this earthquake, but the potential for damage exists, because superstructure units in bridges and overpasses are not adequately connected at hinges and bearings. Severe shaking could cause spans to drop off their supports. Connecting segments of a structure is the preferable method of retrofitting existing bridges. This can be accomplished by connecting the bridge segments together with restrainers consisting of steel cables or rods. Retrofit should be planned starting with overpasses and proceeding with bridges spanning the Nile, until all such structure are at least protected against separation of individual segments. Because of the wide variety of bridges and overpasses, no single type of restrainer can be specified for all conditions. Design of restrainers requires compromises as well as ingenuity. Research in California has established that certain restraining devices are suitable for different types of bridges. The devices proposed were described in an article by Oris D. Degenkolb, in the "Proceedings of the Third Seminar on Repair and Retrofit of Structures", published by the Department of Civil engineering of The University of Michigan, Ann Arbor Michigan 48109, May 1982. A copy of the article is attached (Appendix A) to this report. It is recommended that the General Authority for Roads & Bridges adopt the "American Association of Highway and Transportation Officials Standard Specifications for Highway Bridges", as a guide for the retrofit for bridge and overpass structures in Egypt, although the details provided should be modified as required to meet local conditions.

Summary of Site Inspections

Banha Bridge:

The Banha bridge is located about 60 Kilometers south of Cairo across the Nile. This is a double boxgirder bridge of prestressed reinforced concrete. The east approach consists of 16 spans of 50 meters each. The river is crossed by spans of 69 meters, 120 meters and 69 meters, and the west approach is 4 spans of 50 meters each. The width of the bridge is nearly 60 meters. No damage was suffered by this structure due to the earthquake. It should be noted that the span of 120 meters is substantial, and when a heavy truck crosses, this causes a lot of vibration.

Earlier this year a tanker truck filled with diesel fuel overturned and caused a fire. As a result the reinforcing steel in the bottom of the boxgirder popped out in the last span of the East approach. The cover on the steel was less than 1/2" which is insufficient for rust prevention and protection against fire. The chief inspector had recommended to increase the cover to 2 inches, but this advise was not acted on. During this earthquake this bridge performed well, however a quake of larger magnitude and closer to the bridge site might cause cracking of the concrete resulting in exposure of the steel with rusting and spalling off of concrete. It is recommended to advise the Egyptian authorities to make provisions in the specifications for concrete in long span bridges to increase concrete cover on the steel. Another observation is that the reinforcing steel consists of smooth bars. Deformed bars would be preferable because of better bond characteristics. A more serious problem with this bridge is the fact that it is prestressed. The prestress in the steel is to be transferred to the concrete and load it in compression, thus assuring that heavy loading will not cause tensile stress in the concrete. Having only 1/2" of cover on the prestressed steel has the potential of the thin layer of concrete cracking, negating the advantage of the pre-stress. Further study of this bridge is recommended, and possible remedial measures should be considered.

Abassia Bridge overpass:

This is also a bridge constructed of prestressed concrete, supported by Tee shaped columns and each span has 4 prestressed I-shaped beams. This structure is located close to the center of town. No damage could be detected anywhere.

Delta water control structure (barrage):

Two structures exist at this site. One, a masonry structure dates from 1860, the other downstream barrage dates from 1938, and is constructed of unreinforced mass concrete with 62 openings each 5 meters wide. Only the newer structure is used for water control, and no damage was observed. The older masonry structure has 4 decorative towers, one at each end and two in the middle. The middle towers sustained damage at the top 10 meters of the structure. Both horizontal and vertical cracks were observed, with some horizontal displacement. The condition of the tower with the most damage is such that another quake of the same magnitude could cause it to collapse. The old masonry dam is no longer used to back up the river for irrigation, and is more a tourist attraction. No traffic is permitted on the top of the dam, except bicycles and pedestrians. The parapets are also cracked in several places, but according to the engineer, this happened prior to the earthquake when traffic loading had increased to about 3 times the design loads. For that reason, all traffic now uses the new roadway which is part of the 1938 structure. Except for damage to the towers, the damage observed is minor and only needs patching up.

Kasr de Nile Bridge:

This bridge did not suffer damage to the main structure, but on the west side part of the asphalt roadway cracked and fell out. The slab of asphalt that failed was only about 2 x 6 feet and may have been weakened prior to the quake by heavy traffic. The deck had been repaired when I arrived. The bridge engineer was of the opinion that the deck failure was caused by a faulty joint. No further remedial action is required at this crossing, though it would be advisable to make a detailed inspection of all joints in the bridge deck.

VII. ACKNOWLEDGEMENTS

Numerous individuals contributed to the successful completion of the reconnaissance team's mission. Dr. William H. Smith, Director, Office of Engineering, USAID, Cairo was instrumental to the team's successful investigations and spent long hours coordinating efforts and logistics. Valuable assistance was provided by General Engineer Farouk El Meligi, Deputy in Charge, Central Organization of Reconstruction; Civil Engineer Hazem El-Abd, Chairman of Central Organization for Development and Deputy Minister for Development & Housing- Egypt; Dr. Amira Abdel-Rahman and Dr. Fayrouz El Dib of the Building Research Center of the Ministry of Reconstruction; Dr. Abdel Hussein, Director General, and staff of the Egyptian Geological Survey and Mining Authority; and Dr. Joseph Sidky Michael, Director, and staff of the Helwan Observatory, National Research Institute of Astronomy and Geophysics. Their assistance was invaluable and essential. The manuscript was improved through the suggestions of Drs. E.V. Leyendecker and Robert M. Hamilton of the U.S. Geological Survey.

APPENDIX A

Bridge Retrofitting Details

by

Oris H. Degenkolb

(See section VI, "Bridge/ Barrage Survey " by H. van de Pol for discussion)

BRIDGE RETROFITTING DETAILS

Oris H. Degenkolb

INTRODUCTION

The 1971 San Fernando, California earthquake disclosed the fact that many existing bridges had serious seismic deficiencies. The State of California initiated a survey of all its bridges and determined that approximately 1220 could have their seismic resistance increased by retrofitting them to keep the structural segments from separating when shaken by an earthquake. The total program is estimated to cost approximately $50 million and is now slightly more than half completed.

DESIGN METHODS

California's criteria for designing restraining devices have changed a number of times since the retrofitting program was initiated in 1971. The first criteria was very simple and consisted of providing a restraining force equal to 25% of the dead load of the lighter segment of superstructure connected. An effort was made to use ductile materials.

Bridge seismic design specifications have been revised radically since that time, bridge designers are now able to take advantage of the advancements made in the field of computors and structural dynamics, and Load Factor Design methods have superseded the Working Strength Design method.

Restrainers are now basically designed in accordance with the American Association of Highway and Transportation Officials Standard Specifications for Highway Bridges. The equivalent Static Force Method may be used for designing restrainers for bridges with well balanced spans and supporting bents or piers of equal stiffness, but the Response Spectrum Method applied to the structure as a whole is generally preferred for more unusual structures and where contributing dead loads may come from beyond the immediate spans or frames.

Unless there are other limiting factors, such as the ability of a structure to accommodate the restraining forces, restrainers should be designed to resist forces equal to the acceleration, expressed as a percentage of the gravitational force, times the contributing dead load, but not less than 0.35 times the contributing dead load.

The dynamic analysis utilizes a modal analysis based on the application of the response spectrum of ground acceleration to a lumped sum mass space frame of the structure. This method considers the relationship of the site to active faults, the seismic response of soils at the site, and the dynamic response characteristics of the whole bridge.

Dynamic analyses sometime appear to give what seem to be erratic results. Minimum, or less than minimum, restrainers may be determined to be satisfactory, but more restrainer capability at the same location may be calculated as being insufficient. This apparent inconsistency is due to the fact that a stiffer element in a system will "attract" more force. In specific instances where this phenomena has been observed, restrainers with minimum or greater than minimum capacities have been considered to be the more appropriate. Considering the fact that different methods of analysis give drastically different results, none of which may represent what may happen when a structure is shaken by an actual earthquake, it should be realized that a designer must use a considerable amount of judgment.

RESTRAINER DETAILS

Many compromises must be made in designing seismic restrainers. Ideally, restrainers should:

- Be effective in an earthquake.
- Be economical.
- Dissipate energy.
- Keep units of a structure in their initial relative locations.
- Require no maintenance.
- Be accessible for inspection and repair.
- Be repaired or replaced by ordinary maintenance workers.
- Use ordinary tools for repair or replacement.
- Use commonly available parts which don't become obsolete.
- Not use liquids which can leak out or evaporate.
- Be foolproof.

The basic restrainer materials used for retrofitting California's bridges are 3/4" 6x19 cable (Federal Spec. RR-W-410C) and 1¼" Ø bars (ASTM A-722 with supplementary requirements). The end anchorages for the 3/4" cables (Figure 1) develop the full strength of the cable. Cables have a minimum breaking strength of 46 kips, are assumed to have a yield strength of 39.1 kips, and frequently test to 53 kips ultimate.

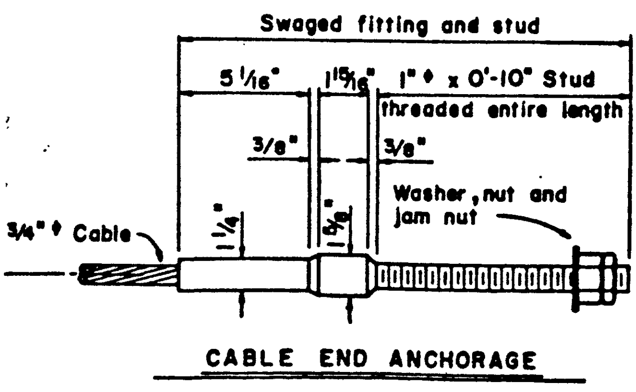


Figure 1

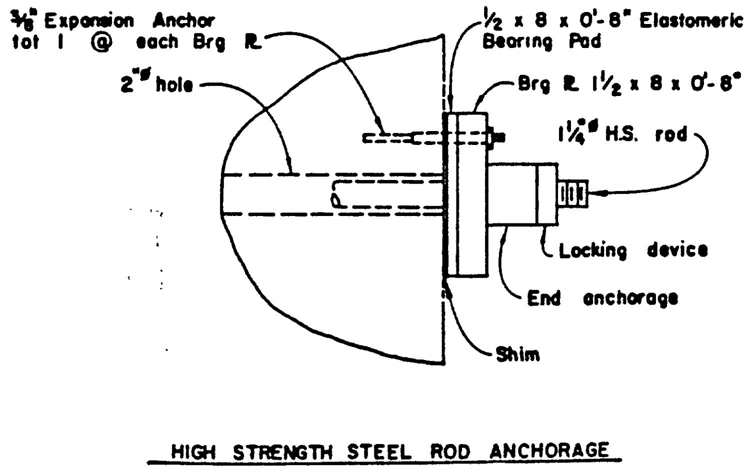


Figure 2

1¼" dia. high strength steel rods are required to have a minimum ultimate strength of 150 kips. The supplementary requirements of ASTM A 722 assure greater ductility. The 1¼ dia. size is readily available competitively, whereas the supply of other sizes may be somewhat limited. The design yield strength is 120 kips and two types of bars are commonly used: Dywidag threadbars, which have a continuous rolled-in pattern of threadlike deformations along their entire lengths, and smooth rods which are cut to length and have machine threaded ends. Although they frequently develop the full strength of the rod, couplers and anchorage devices are required to develop not less than 95% of the specified ultimate tensile strength of the rod. Figure 2 is a diagramatic sketch of a typical end anchorage for high strength steel rods.

Transverse restraining devices in the hinges of older concrete bridges are often considered to be inadequate for keeping the adjacent sections of superstructure aligned during an earthquake. Differential movement between the two sides of a hinge would shear high strength steel rod restrainers. Transverse restrainers (Figure 3) are added when required, to assist in keeping the two sides of a hinge in alignment. The concrete filled pipe transverse restrainers are placed in the direction of normal hinge movements.

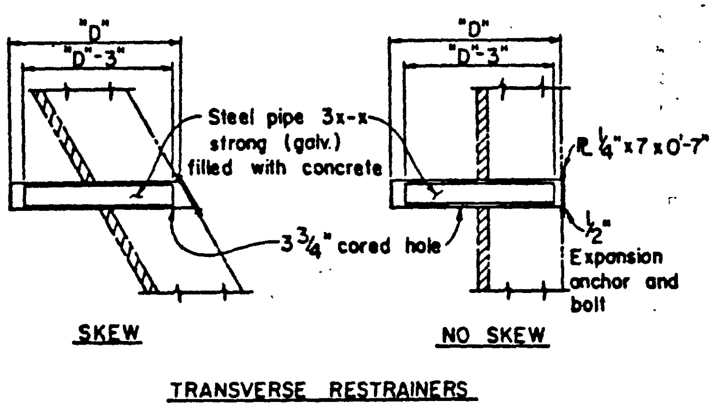


Figure 3

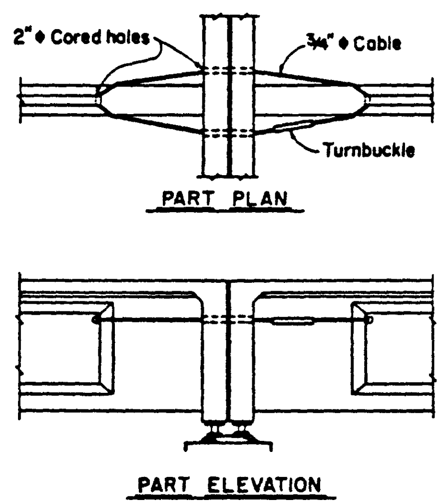


Figure 4

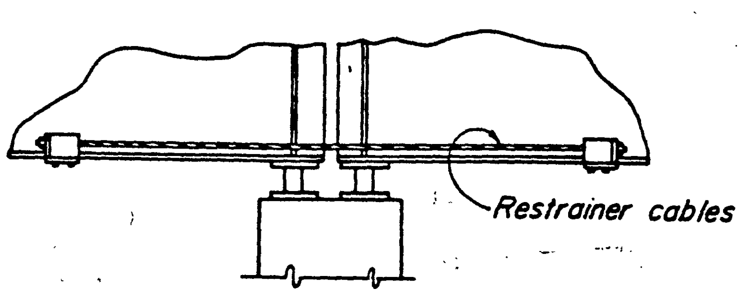


Figure 5

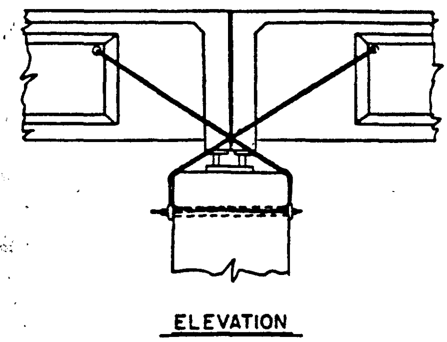


Figure 6

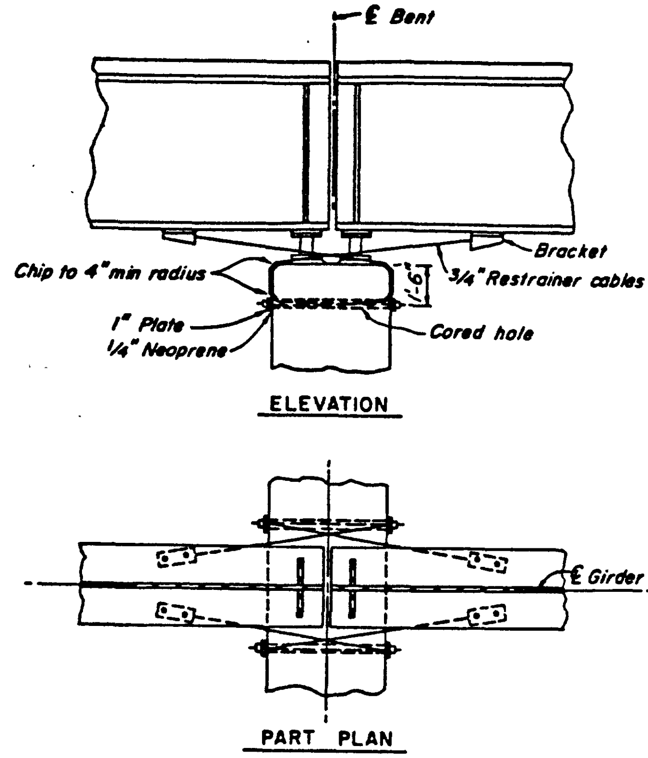


Figure 7

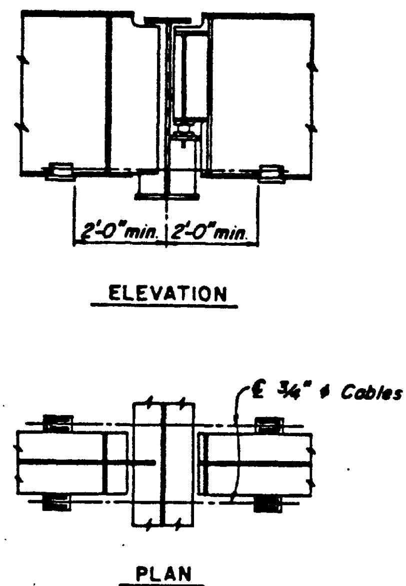
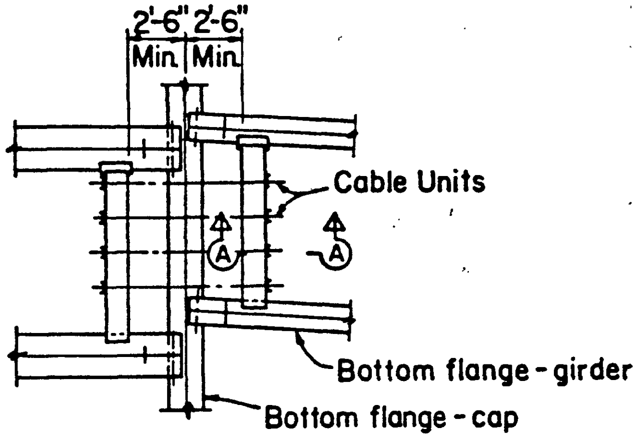


Figure 8

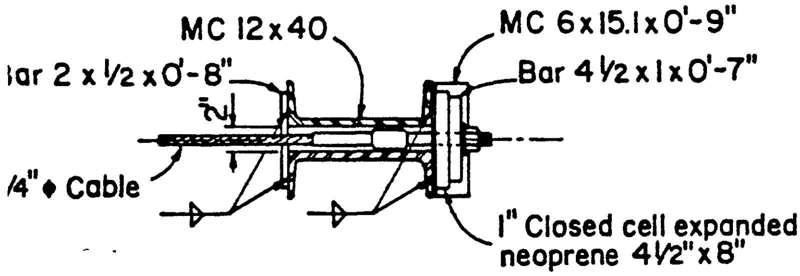
Figures 4 and 5 have been used for connecting segments of superstructures together and are suitable for relatively short structures with wide supports.

Figures 6 and 7 show methods of connecting precast-prestressed and steel girders to bent caps. Although these details are especially suited to long multi-span structures, they are also preferred for shorter structures with few spans. The detail illustrated in Figure 7 may not be suitable in some instances where vertical clearance underneath the structure is critical.

Figure 8 illustrates a method used for connecting steel girders which are supported on a steel girder cap where the girders are in line with each other. In cases where girders cannot be connected directly, because of curved or flared roadways, cable restrainers are attached to beams made up of steel channels which are connected to the bottom girder flanges as shown in Figure 9.

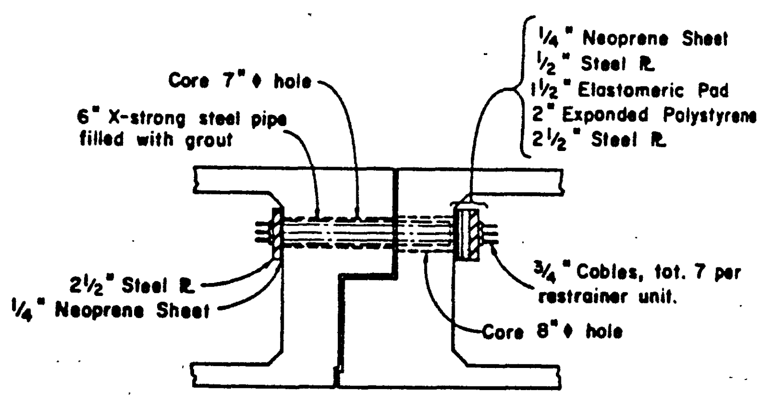


PLAN



SECTION A-A

Figure 9



TYPE H-IA HINGE RESTRAINERS

Figure 10

An early type restrainer which was used in box girder hinges is shown in Figure 10. It had the advantage of providing a considerable amount of transverse and vertical, as well as longitudinal, restraint. It's use is limited, however, because many hinge diaphragms don't have the strength to resist the punching-out effect of the restrainer cable anchorages. Another disadvantage is that the grout, which is placed in the pipe to increase the transverse and vertical shearing capacity, reduces the stretching capacity (ductility) of the cables.

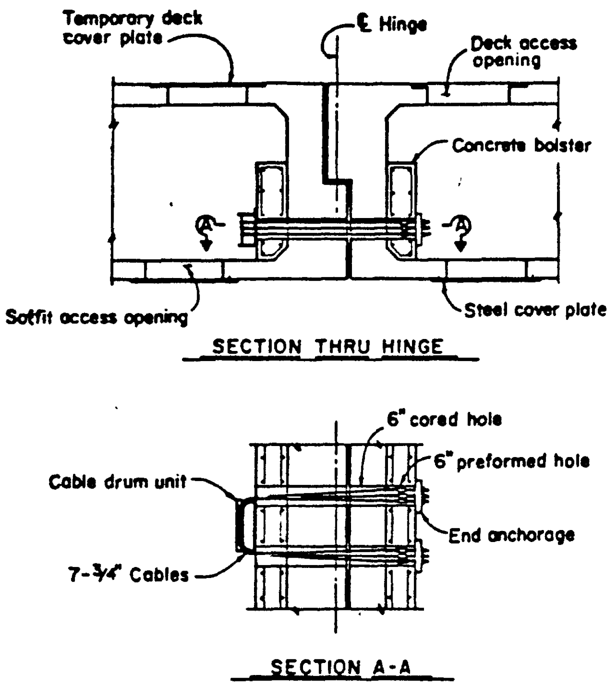


Figure 11

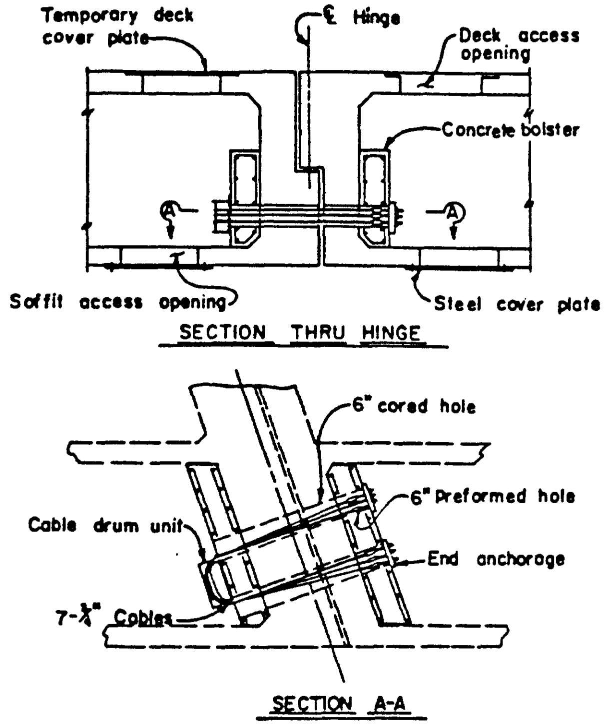


Figure 12

The most commonly used retrofitting detail in California is shown in Figure 11 because of the predominance of concrete box girder bridges. Reinforced concrete bolsters are used to spread out the anchorage forces which would otherwise destroy the hinge diaphragms. Figure 12 is a similar detail which aids in preventing rotation of superstructure segments caused by the skewed ends. The seven cables which are passed twice through the joint give the restraint of 14 cables. Seven cables passing through the hinge three times give the effect of 21 cables, as shown in Figure 13.

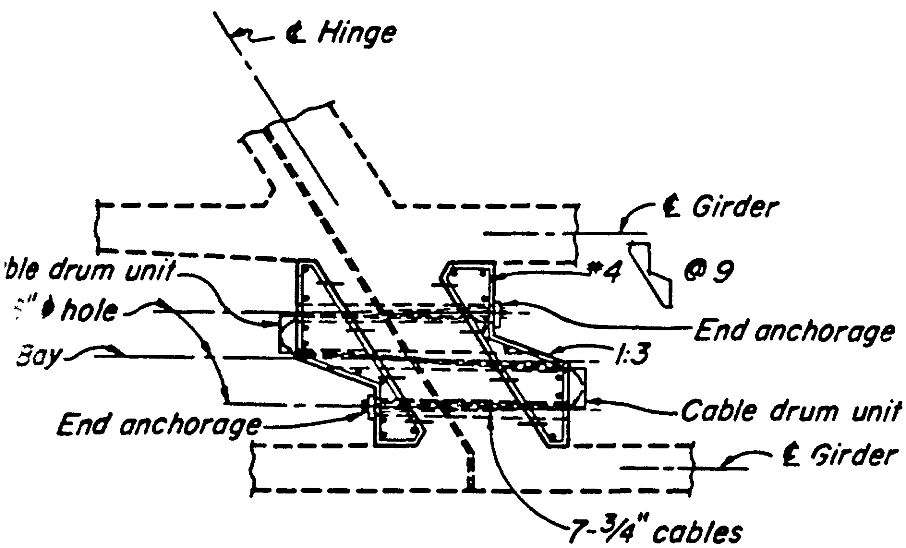


Figure 13

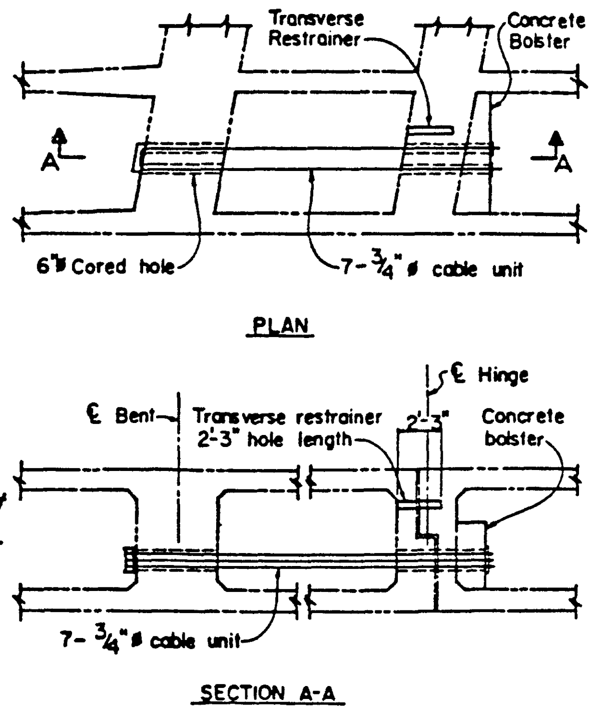


Figure 14

Hinges in box girder bridges are usually located about one-fifth of the span length from a bent. In cases where it is desirable for cables to stretch more than allowed in the previous details, cables are passed all the way through the cantilever end of the span and around the bent cap as shown in Figure 14. This same scheme is also used with rod restrainers. Rods must be longer than an equivalent cable restrainer which provides the same amount of restraint, because of the greater modulus of elasticity. A plan view of rods connecting a hinge to the bent cap of a skewed bridge is shown in Figure 15.

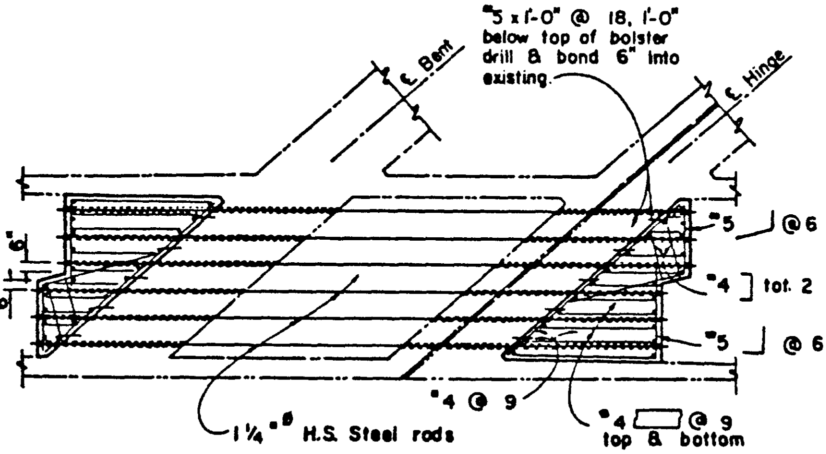
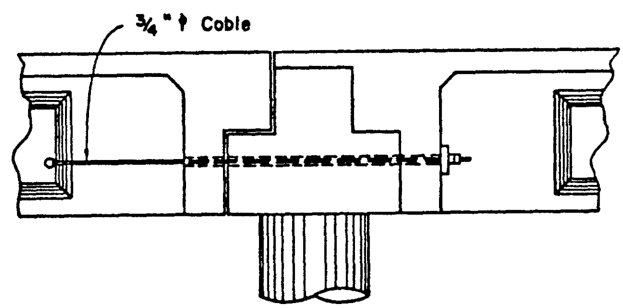


Figure 15



ELEVATION

Figure 16

Although access holes have been made in all three cells, in some contracts, some contractors have found it more economical to omit the access opening in the cantilever cell. They have been successful in aligning the holes through the cap and diaphragm and threading the restrainers through the cantilever cell from the first and third cells. Minor obstructions, caused by supports for the deck forms, can generally be pushed out of the way. Access to the cantilever cells is now optional and at the contractor's expense, if he prefers to use them.

Precast-prestressed girders supported on an "inverted T" cap can be restrained as shown in Figure 16. Coring holes near the ends of prestressed girders present no special problems if the girders are prestressed with strands or wires. Severing a few small tendons will have a negligible effect on the strength of a girder. If girders are tensioned with large rods, precautions should be taken to avoid damaging them.

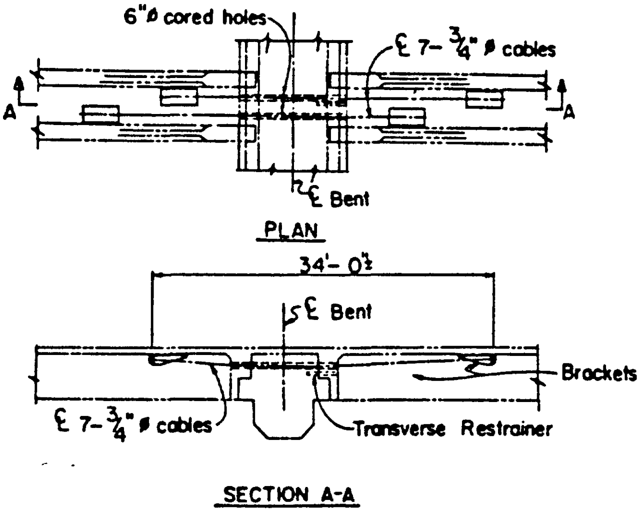


Figure 17

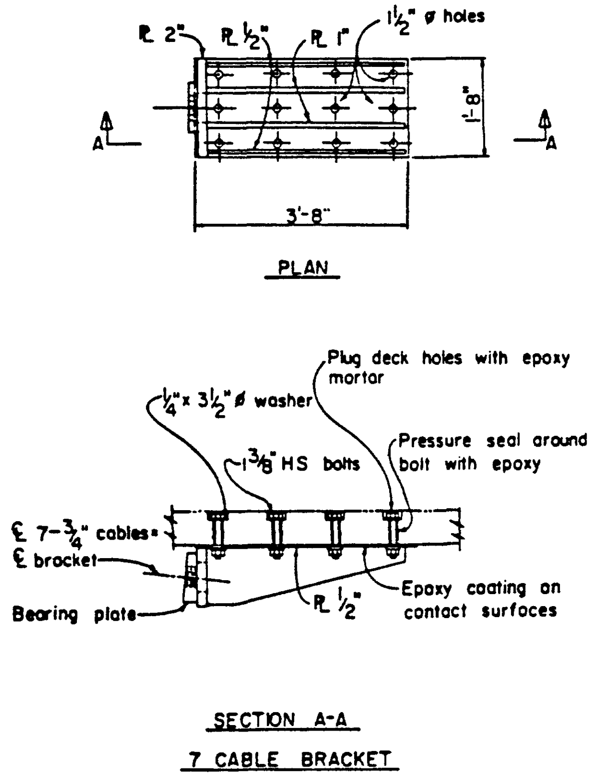


Figure 18

Figures 17 and 18 illustrate a method of restraining precast-prestressed girders at a bent by attaching cable anchorages to the underside of the deck and passing the cables through holes cored through the bent cap where it was considered impractical to attach the anchorages to the girders. Similar schemes have been used using rods in lieu of cables. Care must be taken to avoid damaging main cap reinforcement and not bending restraining rods excessively. Figure 19 shows the same general scheme where it was not practical to attach restrainers to the girders or inadequately reinforced diaphragms.

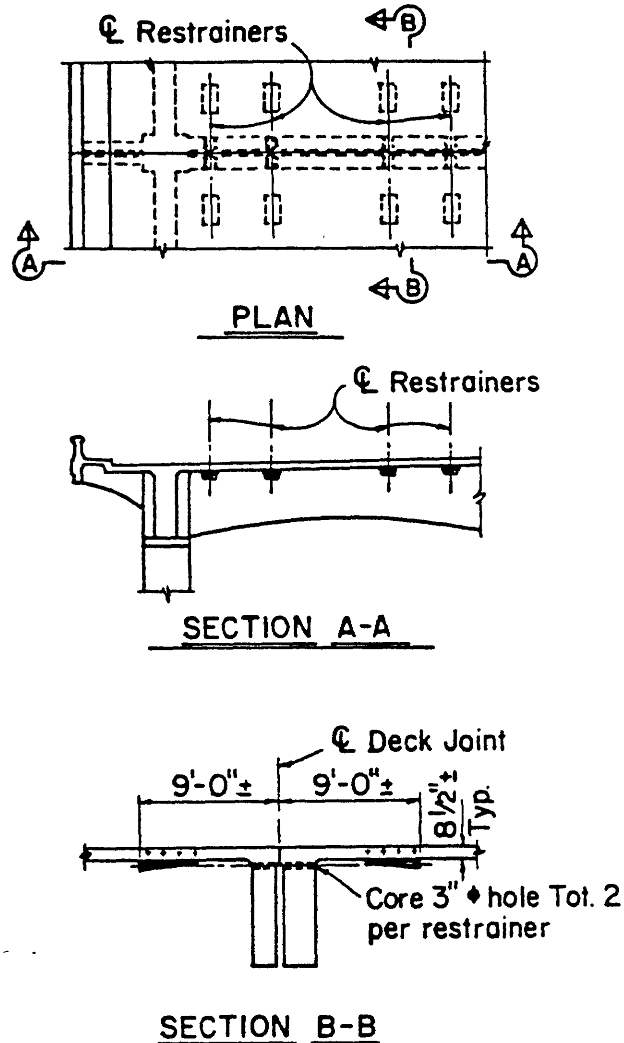


Figure 19

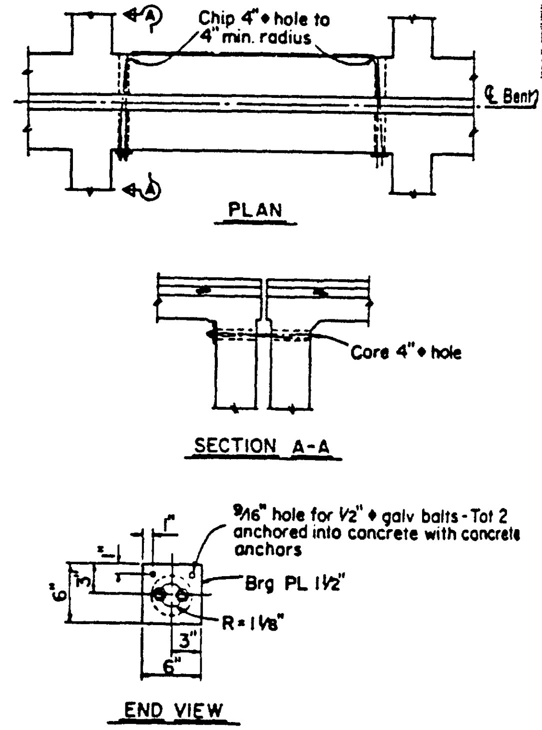


Figure 20

Figure 20 shows a typical restrainer for small T-beam bridges which have only a few spans with wide supports. An identical detail has been used for T-beam bridges with very narrow hinge seats.

Figure 21 is commonly used for T-beam bridges with diaphragms too lightly reinforced to safely resist the required restrainer forces.

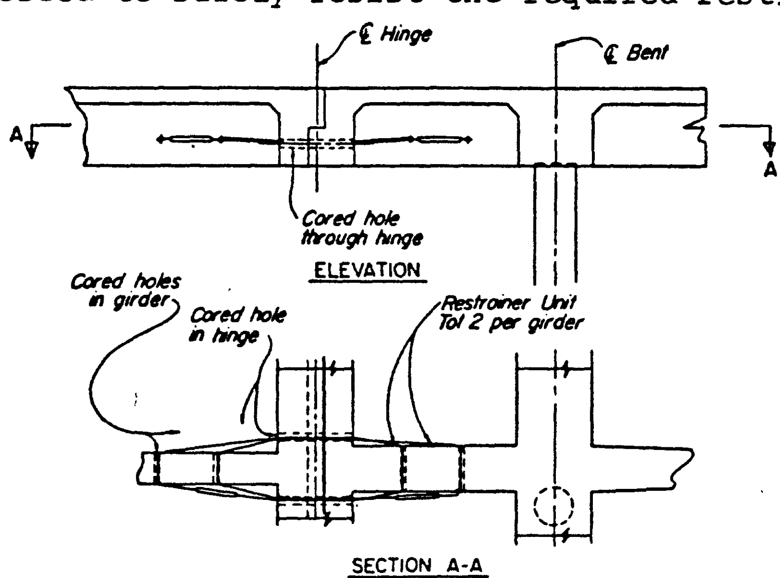


Figure 21

Continuous longitudinally reinforced concrete bridges with hinges are seldom retrofitted because the spans, if unseated in an earthquake, will not fall down under the influence of their own dead load. It is presumed that the problem will be recognized and temporary shoring placed or other remedial action taken before any serious problems occur. Simple spans, drop-in spans, and some specially designed slab bridges which are certain to drop if they become unseated, have been retrofitted.

Figure 22 shows the detail used for restraining a drop-in slab adjacent to a T-beam span. Hinges of special slab bridges have been restrained in an almost identical manner with diagonal holes being cored on both sides of the hinge (similar to the right hand side of Figure 22). The cable ends in those cases were either anchored in the deck or connected with a turnbuckle underneath the deck.

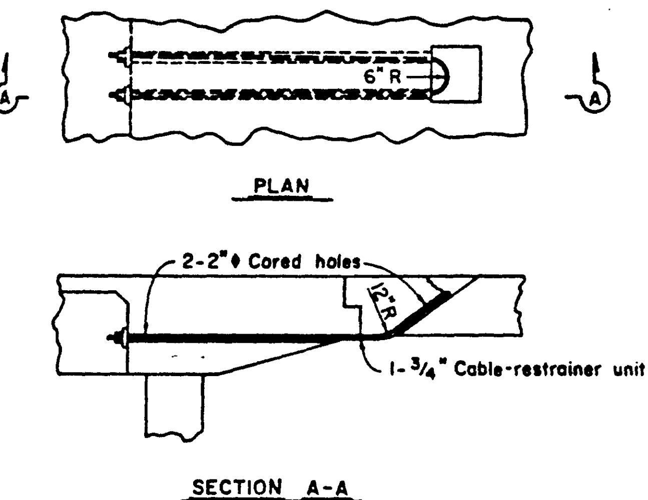


Figure 22

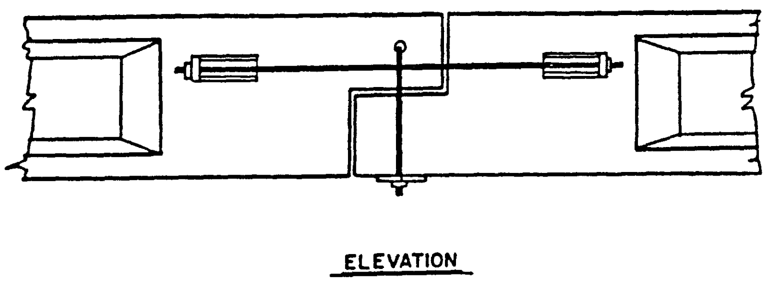


Figure 23

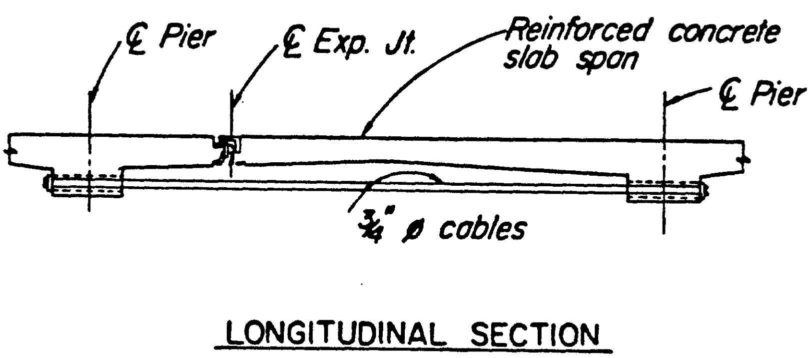


Figure 24

Precast-prestressed girder hinges have been restrained longitudinally and vertically as shown in Figure 23. The possibility of differential lateral movement should be considered also -- especially if the spans are skewed.

Hinges in relatively short spans or short drop-in spans can be restrained by connecting the adjacent piers with restrainers as shown in Figures 24 and 25. One of the main problems with this scheme may be excessive stretching of the tendons if the span is rather long. More tendons can be used to overcome that problem, but that also increases the cost.

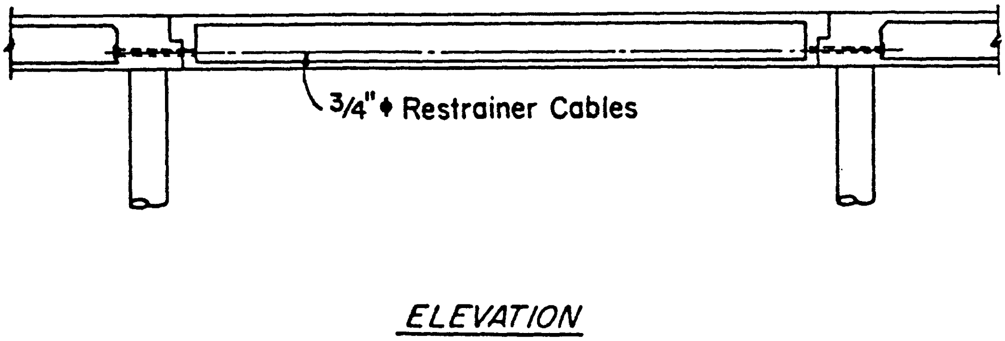


Figure 25

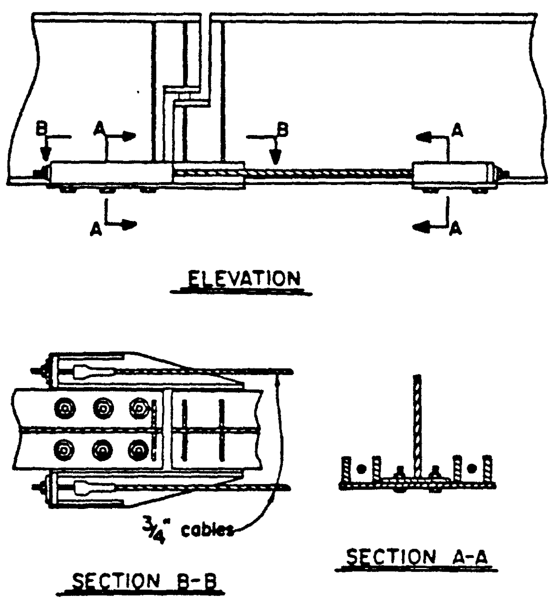


Figure 26

Figure 26 shows a detail for restraining a commonly used steel girder hinge. The welded plate assembly bolted to the bottom flange of the suspended side restrainers excessive transverse and vertical movement. The cables connecting that assembly and a bracket attached to the bottom flange of the cantilever limit the longitudinal opening of the hinge.

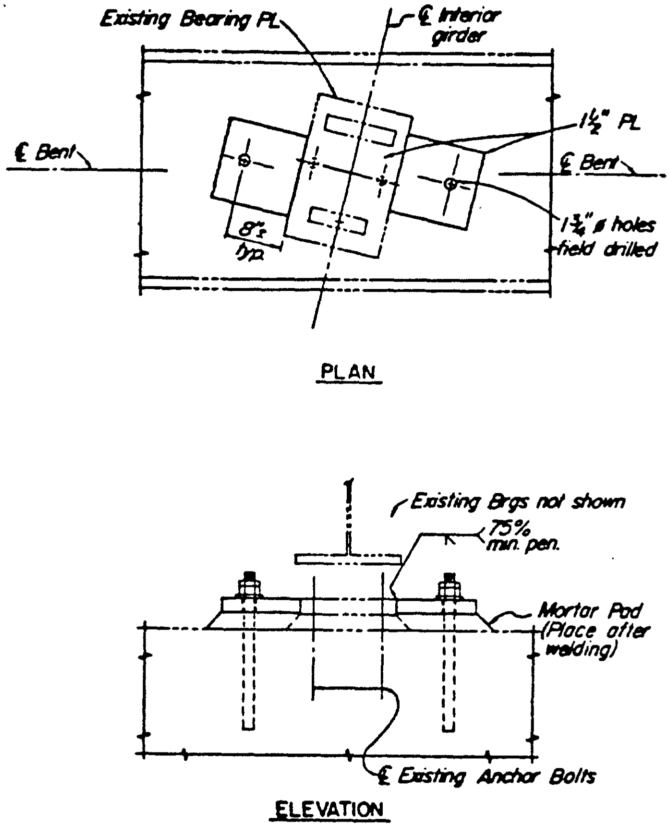


Figure 27

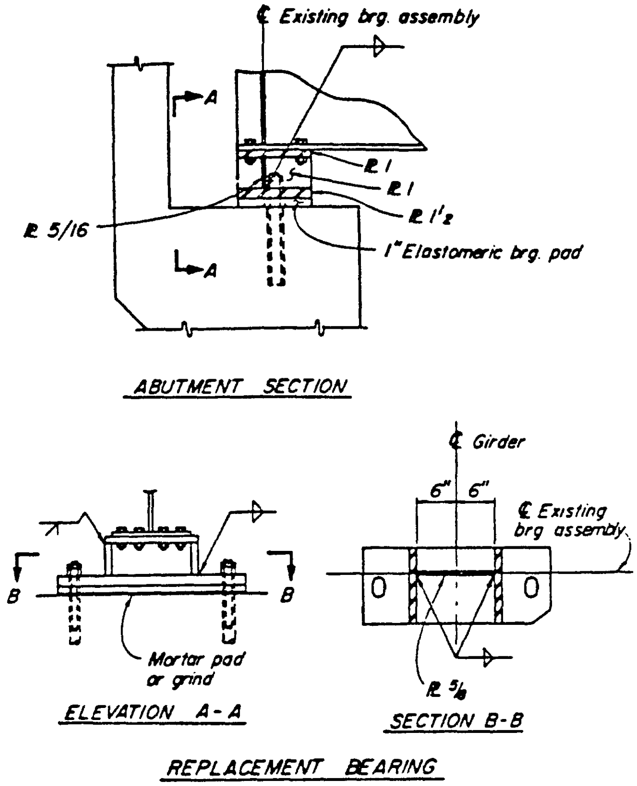


Figure 28

Masonry plate anchor bolts are one of the most seismically vulnerable details. Additional horizontal support has been given to some masonry plates by welding steel plate extensions with additional anchor bolts to existing bearing assemblies, as shown on Figure 27. Other portions of the bearings should be investigated and additional corrective action taken, if necessary, to make certain that there are no equally vulnerable deficiencies remaining. Steel bearings and anchor bolts should be designed to resist at least twice the calculated force that they may be subjected to.

It is sometimes advisable to replace existing steel bearings -- especially if they might allow the bridge to drop more than 6 inches or lead to other failures. This has been done as shown in Figures 28 and 29. Figure 28 shows a steel rocker bearing that was replaced with a welded steel pedestal and elastomeric bearing pad. It may also be necessary to provide additional longitudinal and/or transverse restraint in addition to this detail. Figure 29 illustrates how steel rocker bearings have been replaced by using elastomeric pads for new bearings and reinforced concrete to support the pad and provide transverse restraint. Longitudinal restrainers may also be required in addition to this detail.

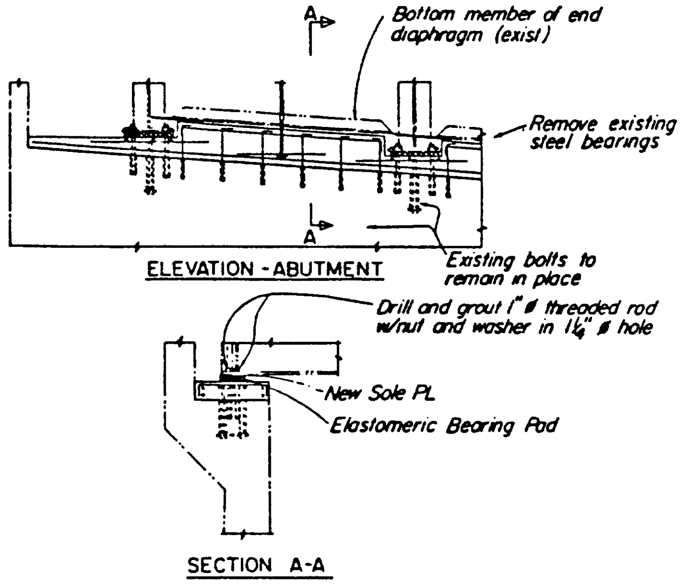


Figure 29

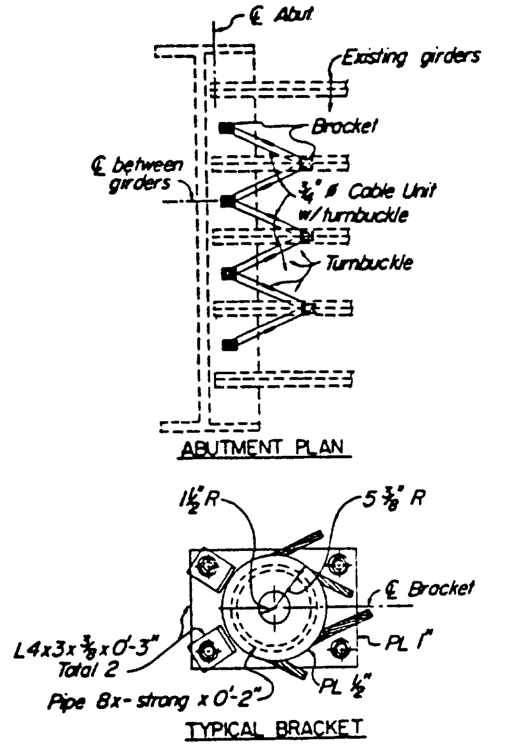


Figure 30

Figure 30 shows how steel girders can be given additional longitudinal and transverse restraint at an abutment. A method used for restraining steel girders transversely is shown in Figure 31.

The solid steel pin shown on Figure 32 will provide transverse and longitudinal restraint at an abutment. One of the main limiting factors for this detail is the strength of the abutment seat and end diaphragm. It is also a good detail for new construction where the concrete can be reinforced to develop the forces imposed by the steel pin. Although this scheme can also be used at intermediate supports there may be large amounts of negative reinforcement in bent caps that would be cut or damaged by coring the vertical holes.

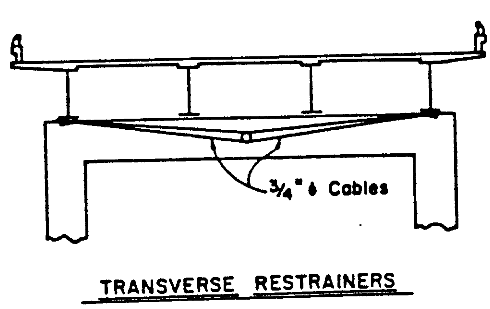


Figure 31

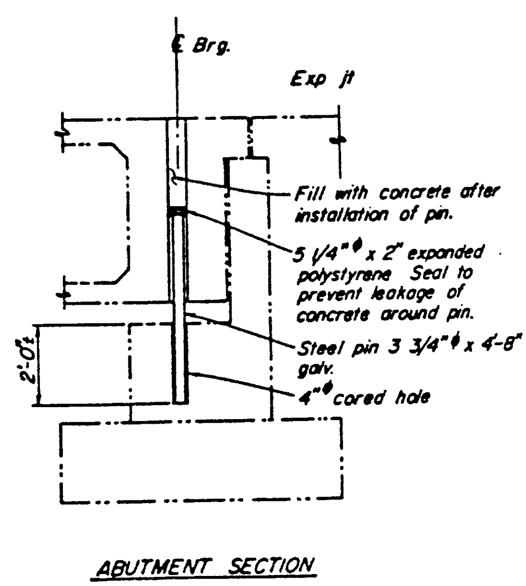


Figure 32

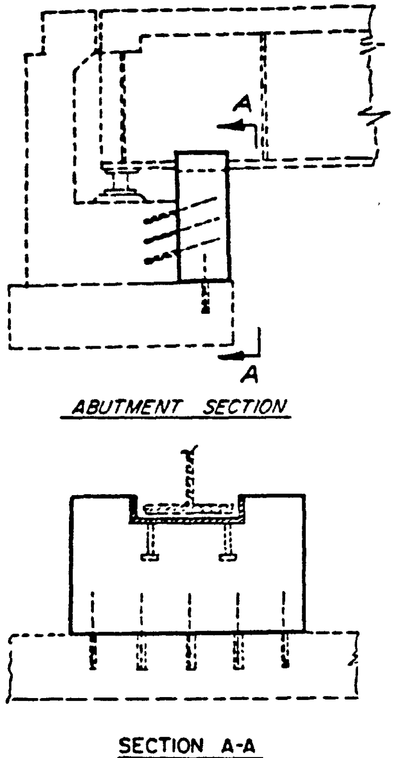


Figure 33

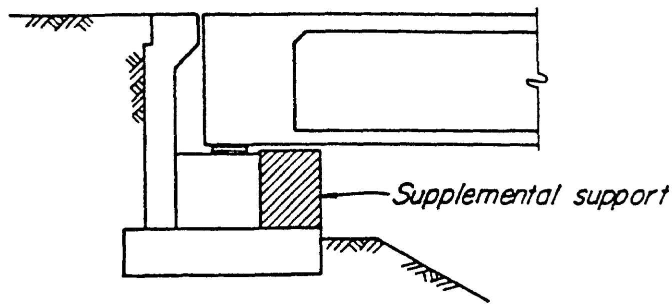


Figure 34

Figures 33 and 34 illustrate methods used for providing supplemental support under the ends of steel or concrete box girders, respectively, when longitudinal movements might exceed the capacity of the bearings.

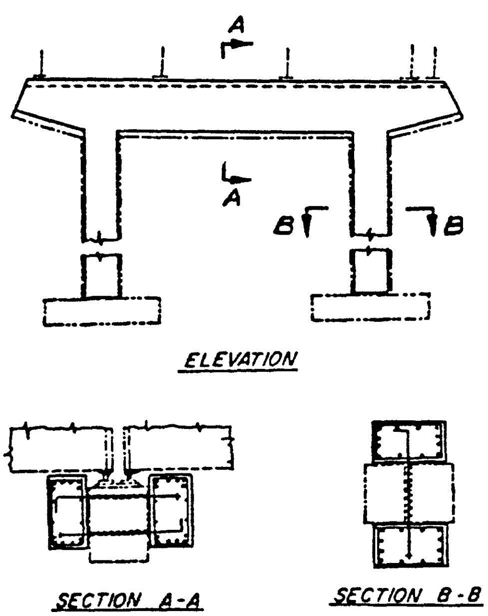


Figure 35

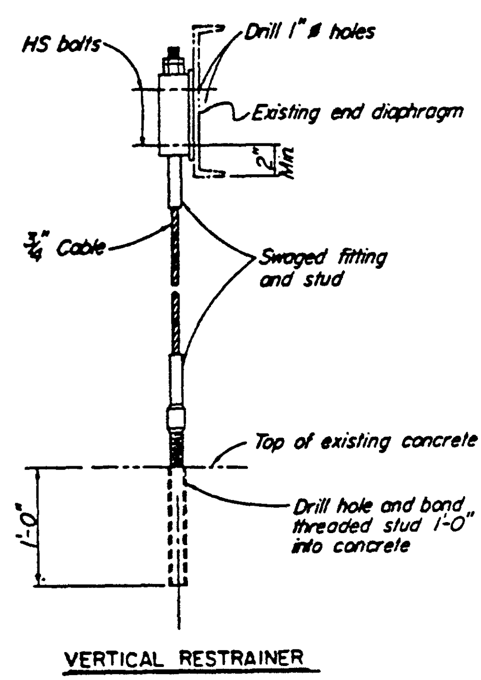


Figure 36

The support width of one bent in the center of a long viaduct was increased as shown in Figure 35. Based on the results of a dynamic analysis, it was felt that it would be advantageous to permit the viaduct to work as two short structures rather than one long one, with provisions for extra movement taken at this bent. Extensions were made on both faces of the cap and two columns to make the bent architecturally compatible with the rest of the structure.

Figure 36 shows a type of vertical restrainer commonly used in steel girder bridges. The upper end is attached to the end diaphragm and the lower end grouted into the top of the bent cap. Care should be taken to avoid the negative reinforcement in the bent cap.

CONCLUSIONS

The wide variety of bridges constructed over a period of many years in a large and varied area such as California makes it virtually impossible to use a few standard details for accomplishing an extensive retrofitting program. The details described in this paper are not necessarily complete in themselves. It is frequently necessary to use more than one detail to restrain a segment of a structure adequately. The combination of different construction materials, span lengths, skews, alignment, framing, vulnerable details, etc., makes it necessary to examine every structure as a unique problem.