Structural Eng./Earthquake Eng., JSCE, Vol. 21, No. 1, 57s—65s, 2004 April
(J. Struct. Mech. Earthquake Eng., JSCE, No. 759/ I —67)

STRUCTURAL AND GEOTECHNICAL ASPECTS OF THE 1995 GULF OF AQABA EARTHQUAKE

Mohamed A. H. ABDEL-HALIM[1] and Eid AL-TARAZI[2]

1 Department of Civil Engineering, Jordan University of Science and Technology, Irbid-Jordan
E-mail: shiyab@squ.edu.om
[2] Department of Earth and Environmental Sciences, Hashemite University, Zarqa-Jordan
E-mail: eid@hu.edu.jo

A swarm of earthquakes began in the northern portion of the Gulf of Aqaba on November 22, 1995 with amaximum local wave magnitude of M_L 6.2 and focal depth of about 15 km, causing damage to buildings in the Aqaba region. More than 8000 after shocks were recorded during the next 40 days. Observations related to damage to structures and soil liquefaction are presented by photos and discussed. Generally, engineered low-rise buildings with one to four stories above ground behaved satisfactorily. The hotel area in Aqaba on the shoreline appears to be riskier for flexible buildings during major earthquakes. Therefore, denser inland alluviums or rock sites should be considered for constructing new high-rise buildings and hotels.

Key Words : earthquakes, damage, concrete, construction, structures, performance, structural design

1. TECTONIC SETTING

Aqaba City lies at the northern part of the Gulf of Aqaba that is 180 km long. This Gulf is considered part of the Syrian - African rift system. The Gulf of Aqaba is of particular interest because it is one of the two places in the world where a mid-ocean ridge system changes into a transform system and runs into a continent[1)]. The Gulf of Aqaba occupies the southern part of the Jordan Dead Sea rift, which was formed by Cenozoic breakup of the once continuous Arabian - African Platform[1)]. This rift is a plate boundary of the transform type as shown by **Fig.1**. It connects the Red Sea, where sea - floor spreading occurs, with the Zagros - Taurus Zone of continental collision. The transform fault has a slight component of opening. As a result, part of its length is marked by prominent morphotectonic depressions, the Gulf of Aqaba being the most spectacular[2)]. The Dead Sea rift developed in two stages. The first stage with 65 km of left lateral slip probably occurred some time in the Miocene age[2)]. The second and younger one was developed 4 to 5 Ma ago, and a left lateral slip of approximately 40-km took place. Through the Gulf of Aqaba five morphotectonic trenches can be determined Eilat, Aragonese, Arnona, Dakar, and Tiran, from north to south respectively[1)]. The structure of the Gulf is controlled by faulting which has produced rhomb - shaped grabens as shown in **Fig.1**.

2. HISTORICAL EARTHQUAKES

The Gulf region has experienced numerous moderate earthquakes with associated aftershock sequences, and some significant earthquake swarm[3)]. Poirier and Taher[4)] cite three major earthquakes with intensities of VIII–IX, according to the modified Mercalli scale (MMI), having been felt in Aqaba and Eilat cities in 1068, 1212, and 1588. Ambrasyes and Melville[5)] describe effects of the three large earthquakes in 873, 1068 and 1588. The 873 quake reportedly killed a great number of tribesmen in the desert. The 1068 shock killed 20,000 people in Eilat and destroyed the city. The earthquake in 1588 caused damage in Eilat and the collapse of the monastery at Saint Catherine in Sinai.

Between January 21 and April 20, 1983, more than 500 earthquakes with local wave magnitude of M_L = 4.8 or smaller occurred in the Gulf of Aqaba area[6)]. The strongest shocks were felt in towns on the Gulf and caused widespread concern. Fault - plane solutions indicated strike - slip movement on NE - trending planes, which corresponds spatially with NE - striking mapped faults in the vicinity of the swarm and with a NW - trending dike system.

Alamri et al.[7)] analyzed about 40 events which had occurred during 1985 - 1988. Based on a composite fault - plane solution, he concluded that the Eilat trench is characterized by tensional stresses with vertical as well as NNE - trending, strike - slip movements.

An intensive earthquake swarm occurred during

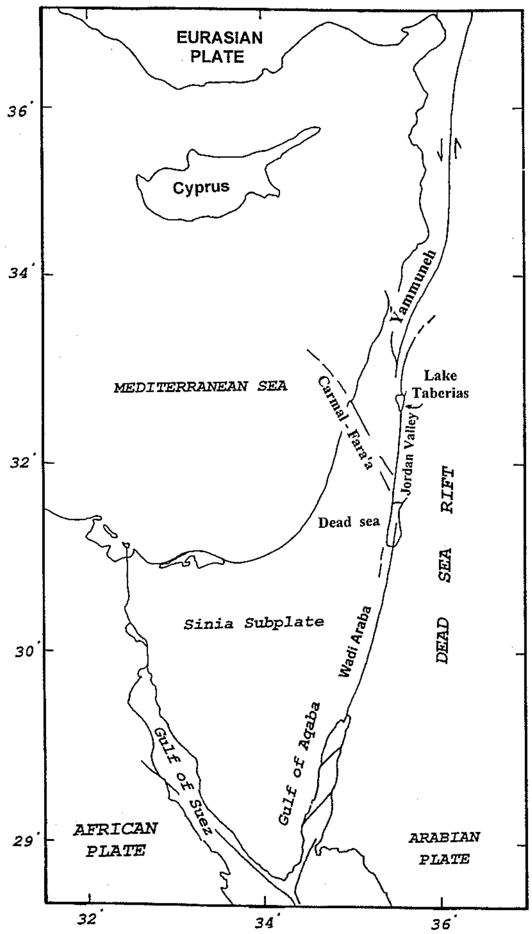

Fig.1 Tectonic Setting of the Gulf of Aqaba.

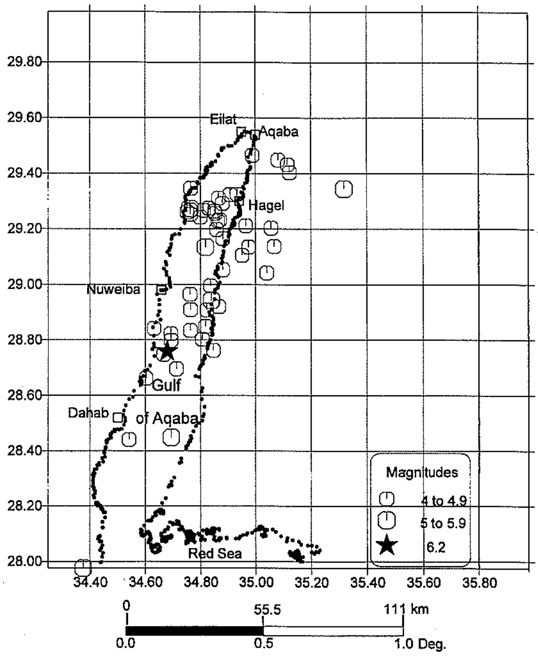

Fig.2 Epicentral Map of the Major and Felt-after shocks of the November 22, 1995 Earthquake[9].

August 1993 - February 1994 and was associated with more than 1200 located events[8]. This earthquake sequence occupied mainly the Aragoneze trench, south of the Eilat trench. Source parameters of this swarm show that stress drops were mostly confined to 1-100 bar range, yet show dependency on the magnitude and source radius.

The major earthquake of 22 November 1995 was the beginning of the last and strongest swarm that ended on 30 December 1997 where more than 2000 earthquakes were observed as shown by **Fig.2** with magnitudes ranging between 2 to 5.2 on the local Richter scale[9]. An important aspect of the earthquake swarm sequences in the gulf is the spacial distribution overlapping of the 1995 swarm with earthquake sequences in 1983, 1991, 1993, and 1994 and the migration of the epicenters northeastward into the land confirming the continued motion of the epicenter along the Arabian plate boundary.

3. THE 1995 MAJOR EARTHQUAKE

The Gulf of Aqaba earthquake woke up many people on the early morning of Wednesday, November 22, 1995. It hit the Aqaba region at 6:16 am local time with a reported local wave magnitude of 6.2 on the Richter scale[9]. The epicenter was located at 28.76° N 34.63° E between the cities of Dahab and Nuweiba about 100 km south-west of Aqaba City. The focal depth of the earthquake was about 15 km. The shaking was felt as far as the northern border of Sudan in the south and Lebanon and Syria in the north, and it continued for about two minutes.

This event was followed by several aftershocks. The strongest was on November 23, 1995, at 00:17 am with a magnitude of 5.2 on the Richter scale. Although the earthquake was felt in Amman and several other adjacent cities, most of the damage was concentrated in the city of Nuweiba (Egypt). Damage was also reported in other cities along the Gulf of Aqaba, including Sharm El-Sheikh and Dahab in Egypt as well as the cities of Aqaba (Jordan), Tabuk and Haql (Saudi Arabia) and Eilat (Israel).

4. RECORDED GROUND MOTIONS

Recordings of the earthquake ground motions were obtained at stations maintained by the Jordan Seismological Observatory, the Natural Resources Authority,

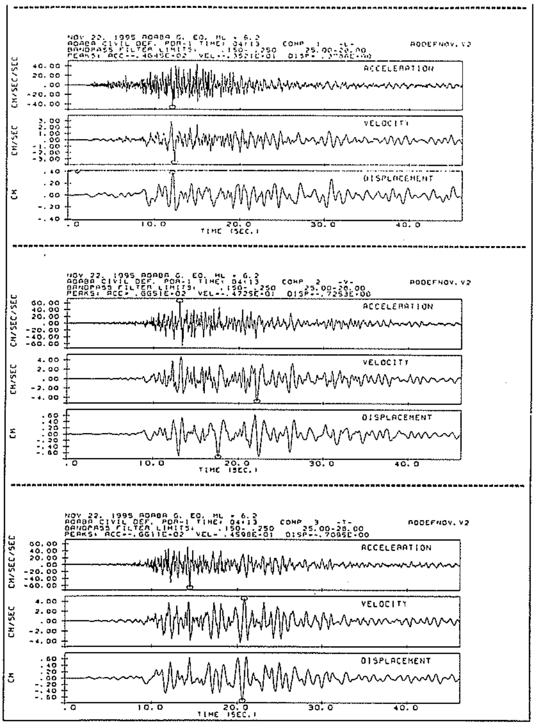

Fig.3 Accelerograms of the three components recorded at Aqaba Civil Defense Station for the November 22, 1995 Earthquake, M_s = 7.3[9].

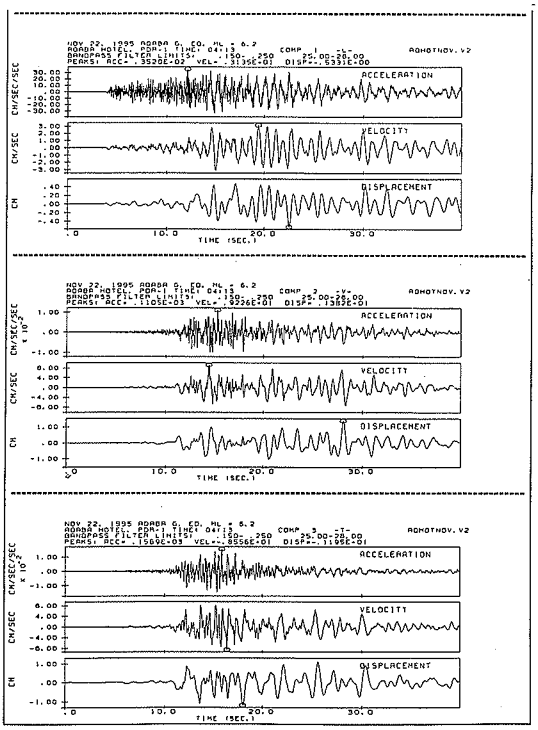

Fig.4 Accelerograms of the three components recorded at Aqaba Hotel Station for the November 22, 1995 Earthquake, M_s = 7.3[9].

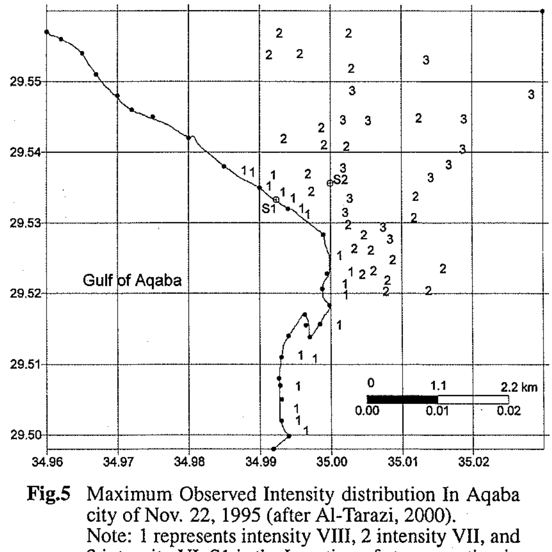

Fig.5 Maximum Observed Intensity distribution In Aqaba city of Nov. 22, 1995 (after Al-Tarazi, 2000). Note: 1 represents intensity VIII, 2 intensity VII, and 3 intensity VI. S1 is the Location of strong motion in the Hotel, while S2 is the second station in the Civil Defense building.

Jordan. Strong motion records were obtained during the main shock at the basement of Aqaba Civil Defense building S2 located about 1.0 km from the shoreline, and Aqaba Hotel building on the coastline S1. The number of stories of the two buildings is the same. The records of these two stations shall serve in comparing the response near the shoreline (where deep medium dense sandy layers exist), with that inland (where shallower and denser silty-sand layers exist). **Fig.3** and **Fig.4** show the accelerograms obtained from these two stations.

The Peak Ground Acceleration of the transverse component of the Aqaba Hotel building is equal to 157 cm/s^2, compared with the same component of the Aqaba Civil Defense building, which is equal to 66 cm/s^2. The ratio between these two values is 2.34:1. This is consistent with recordings elsewhere[10] and[11]. In analyzing Little Skull Mountain earthquake of 5.6 magnitude, Su et al.[11] found that ground motion on alluvial sites is much larger than on rock sites, particularly at low frequencies. From power spectral densities established for the Aqaba earthquakes[12], it has been found that for the main event of November 22, 1995 the predominant frequency content is at about 1 Hz. This supports the high site amplification at the seashore site.

The distribution of the maximum observed intensity (MMI) in Aqaba city, shown in **Fig.5**, also demonstrates the local site effects, where VIII degree on MMI were observed along the shoreline near site S1, while lower intensity VI were observed in the northern part of the city near S2 location.

5. SAND LIQUEFACTION

Liquefaction is defined as a phenomenon whereby a saturated sandy layer loses its shear strength owing to earthquake motion and behaves

Like liquefied soil, according to Wakabayashi[13]. When a saturated sandy layer is subjected to reversed shear, pore-water pressure increases and in turn decreases the effective stress of the sand. When shear strength is reduced to zero, liquefaction occurs.

Many earthquake reports refer to such liquefaction. In the Superstition Hills Earthquakes of 1987 ground liquefaction and soil instability were observed in fields in Imperial, H. J. Degenkolb Associates[14]. In Kobe Earthquake of 1995 liquefaction caused up to 3 m of ground deformation, sunk quay walls, broke gas and water lines, shifted buildings foundations, toppled gantry container cranes and shut down 179 of 186 berths at the port[15].

In this Earthquake, in the hotels area on the shoreline, liquefaction possibly caused ground deformations, and crushed most of the jetties and slabs on the ground beside the shore line into pieces, as shown in **Fig.6**, **Fig.7**. Ground subsidence, differential settlement, and fissures were observed in the slabs constructed on the ground in this area. The relative settlement in these slabs vary from 10 to 20 cm and the fissures were as wide as 10 cm, as shown by the previously mentioned figures. Also, it was noticed that more damage occurred in the hotels area than any other area in Aqaba city.

At the port of the Egyptian city Nuweiba, on the Sinai Peninsula, two out of four berths were severely damaged. Significant rotation of the quay walls toward the sea occurred, leading to separation between the capping beam and the backfill, as shown in **Fig.8**[16]. Settlement of the apron slabs was excessive. Failure of these berths was due to the development of excessive pore water pressure that caused tilting of the quay walls and rupture of the concrete apron slab. Witnesses reported that fountains of water sprung from the sand carrying fine particles of sand. Based on the available evidence and from examining the soil particles covering the apron slabs, it was concluded that soil liquefaction and soil boiling occurred in the backfilling material[16].

Beside the hotels area, on the shoreline, there is an old historical city called Ayla City which is believed to have sunk (**Fig.9** and **Fig.10**) in the ground by the action of historical earthquakes, Ghawanmeh[17].

Fig.6 Ground deformation caused crushing of the floor slabs in structures built on the shoreline.

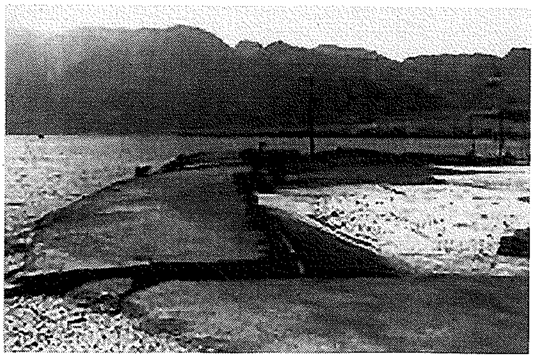

Fig.8 Damage to berths at the port of Nuweiba, Egypt[16].

Fig.7 Ground deformation caused cracking and fragmentation of floor slabs beside the shoreline.

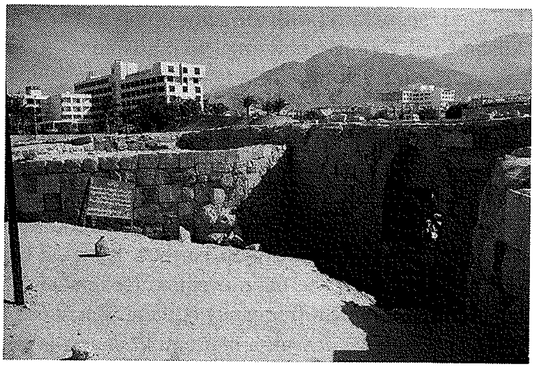

Fig.9 Sunk walls in the historical Ayla City on the northern shoreline of Aqaba.

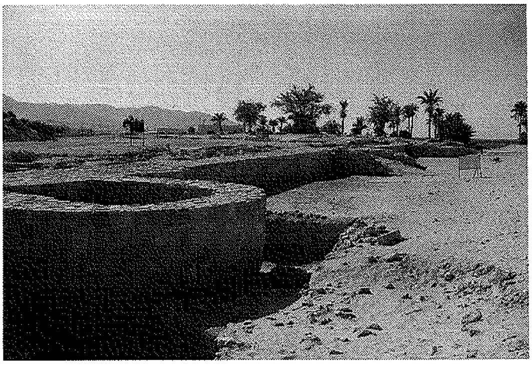

Fig.10 Other sunk walls in the historical Ayla City on the northern shoreline of Aqaba.

Fig.11 Construction of poor quality. The columns were stopped one meter before the concrete slab, and the highest portion of the wall was made from plain concrete supported on hollow block pedestals.

6. STRUCTURAL PERFORMANCE

The damage was widespread over large area and reported in several cities on the Gulf. It vaies significantly from relatively light damage in the cities of Sharm Al-sheik (Egypt), Eilat (Israel), and Aqaba (Jordan) to heavy damage in the cities of Nuweiba (Egypt) and Haql (Saudi Arabia)[16]. The following sections summarize the damage caused by this event in Aqaba city, Jordan.

(1) Types of structures

Aqaba city is the main city in the southern region of Jordan and has a population of about 52000. Most of the building structures in Aqaba consist of reinforced concrete frames in-filled with hollow masonry blocks. The majority of these buildings are low-rise buildings with one to four stories above ground. Except governmental ones, these buildings are with at most, if any, little engineering input. Hotel buildings, in the northern part of the city, are medium-rise buildings ranging from five to eight stories. All concrete elements in these buildings are cast-in-place. The city is built on poorly graded sand containing small percentages of gravel and fines. At greater depths and near the shoreline the soil is mainly porous corals with small shells.

(2) Damaged buildings

Varying degrees of structural and nonstructural damages were inflicted on numerous reinforced concrete buildings during the earthquake. In touring the city, it was witnessed that more damage occurred for the buildings in the hotel area than in any other area in Aqaba city. Most of the buildings which suffered from structural damage were located in the hotel area, and again this is possibly because of liquefaction. For other areas in the city, the damage in structural members was light, however; nonstructural damage was widespread over public residential buildings and

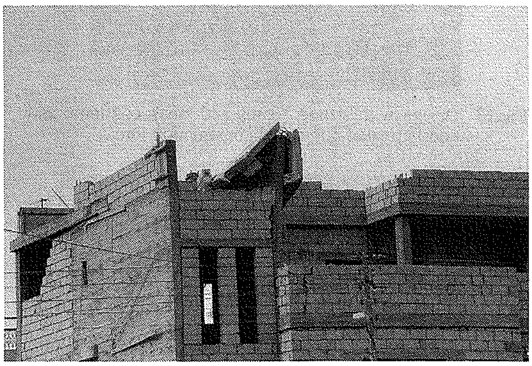

Fig.12 Construction of poor quality: The covering slab of the staircase was simply resting on hollow masonry block walls and poorly connected to the columns.

some of the governmental buildings. Cracks in partition walls and around expansion joints in most of the buildings were observed. In most of these one or more of the following conditions were observed.

1. Construction of poor concrete and detailing: In the staircase of one of the residential buildings, the columns were ended one meter before the covering slab and they were not connected to any beams. In addition, the highest portion of the wall was constructed with a heavy plain concrete section supported on hollow block pedestals, as shown by **Fig.11**. In another residential building, the covering slab of the staircase was resting simply on hollow masonry block walls and poorly connected to the columns, as shown by **Fig.12**.
2. Design with strong beams and weak columns: **Fig.13** illustrates shear failure of a column in one of the hotels buildings which clearly had a strong beam relative to the supporting column and a poorly treated horizontal construction joint.
3. Narrow expansion joints: **Fig.14** illustrates

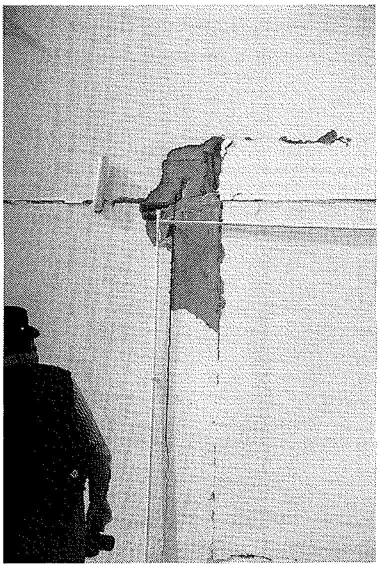

Fig.13 Design with strong beams and weak columns, and poorly treated horizontal construction joint.

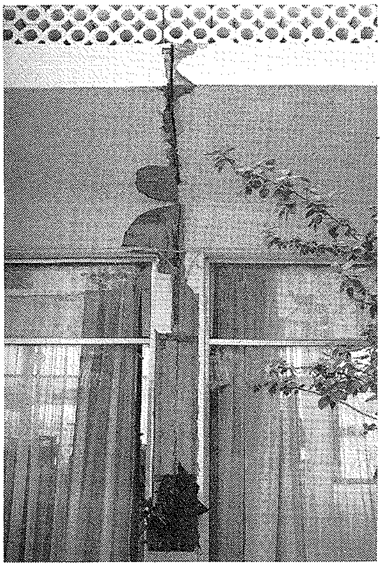

Fig.14 Narrow expansion vertical joints caused pounding between two wings for one of the hotels building.

the effect of narrow expansion vertical joints, which caused pounding between two wings of one of the hotel buildings.

4. Design with stiffer upper parts supported on weakly braced, relatively long columns to provide room for shops, lobbies, and the like. **Fig.15** illustrates this type of design deficiency, which caused the concrete at the top of the columns to be crushed.
5. Separation of secondary members such as emergency exterior stairs which were poorly connected to the building, as shown by **Fig.16**.

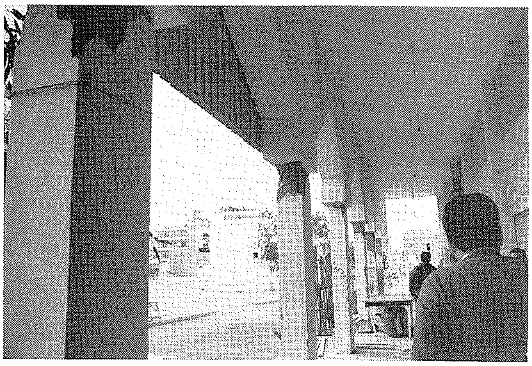

Fig.15 Design with stiffer upper parts supported on weakly braced, relatively long columns which helps give room for shops, lobbies and the like, caused crushing at the tops of the reinforced concrete columns.

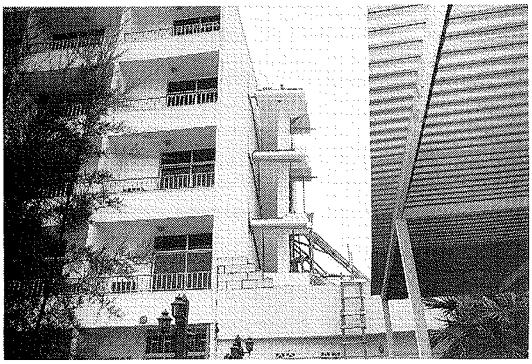

Fig.16 Separation of a poorly connected emergency exterior stair.

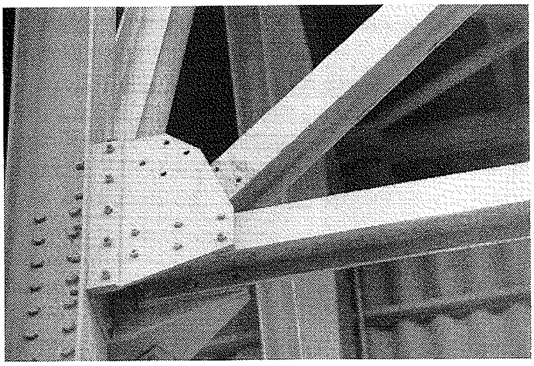

Fig.17 Shearing of the bolts in one of the connections in the Industrial Complex of the Jordan Phosphate Mines Company.

6. Failure occurred in some bolted connections for one of the trusses in the Industrial Complex of the Jordan Phosphate Mines Company. Failure occurred by shearing of the bolts on the plane between the gusset plate and the diagonal member (single shear) as shown in **Fig.17**.

(3) Al-Alamieh housing units

Most of the apartment buildings in Al-alamieh area in Aqaba city are designed and supervised by the Ministry of Public works and Housing in Jordan. The majority of these buildings are low-rise monolithic reinforced concrete buildings with three to four stories above ground. All the columns and beams forming the framing system are cast in place concrete. The frames are in-filled with 100 mm partition walls made from unreinforced hollow block masonry. The buildings survived the earthquake without structural damage.

In order to assess the vulnerability of these low-rise monolithic reinforced concrete buildings for damaging ground motion, the format presented by Shiga et al.[18] was used. This format has been chosen because the required data are easily acquired and the required calculations are easily made. In their treatment, Shiga et al.[18] proposed a critical attribute for seismic vulnerability that was expressed as the weight of the structure divided by the sum of the cross-sectional areas of the columns and the walls at the base.

Typical plan dimensions for one of these buildings is shown in **Fig.18**. The floor area for each story is equal to 305 m^2 and the building has four stories with a story height equal to 3 m. The building incorporates 32 columns and no shear walls. Typical cross-sectional dimensions of one of these columns are 25 × 60 cm, giving a cross-sectional area equal to 1500 cm^2 for each column. Total weight of the building is 13000 kN. Therefore, the seismic vulnerability index according to Shiga et al. format[17] is equal to $13000/(32\times1500) = 0.271$ kN/cm^2, which represents no damage state.

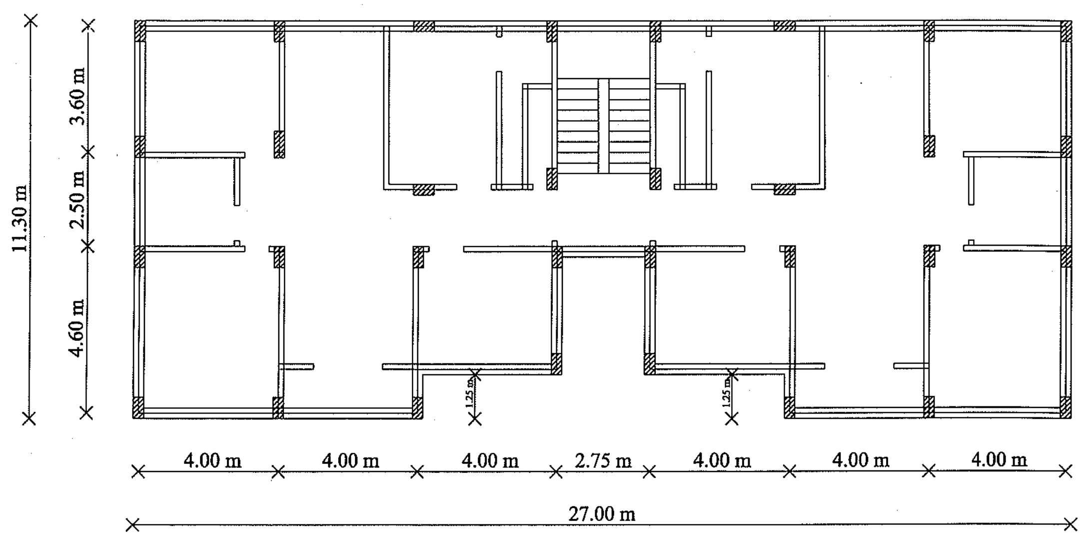

Fig.18 Typical Plan for One of the Al-Alamieh Housing Buildings.

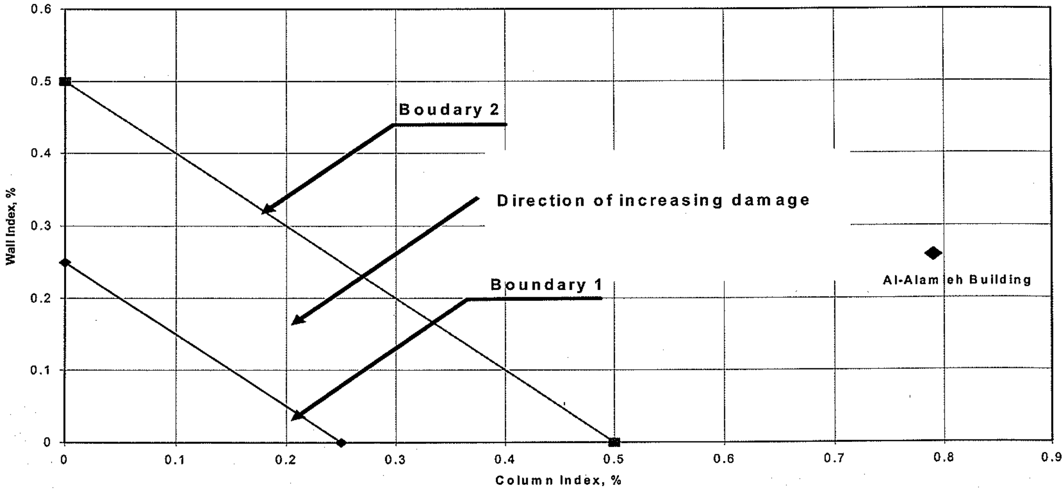

Fig.19 Proposed Evaluation Method[19].

Also, the seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes developed by Hassan and Sozen[19] was used. The format developed by Hassan and Sozen is shown in **Fig.19**. In this figure, each building is represented by a point in a two coordinate representation. The y-axis represents the "wall index," WI, which is defined as the ratio

$$WI = (A_{wt}/A_{ft}) \times 100 \qquad (1)$$

Where

$A_{wt} = A_{cw} + A_{mw}/10$ = effective cross-sectional area of walls in a given horizontal direction.

A_{cw} = total cross-sectional area of reinforced concrete walls in one horizontal direction at base.

A_{mw} = cross-sectional area of nonreinforced masonry filler walls in one horizontal direction at base.

A_{ft} = total floor area above base in a building.

The x-axis represents the "column index," which is the ratio

$$CI = (A_{ce}/A_{ft}) \times 100 \qquad (2)$$

Where

$A_{ce} = A_{col}/2$ = effective cross-sectional area of columns at base.

A_{col} = total cross-sectional area of columns above base.

For the building under consideration, in the short-direction, WI = 0.26 and CI = 0.79. When the building was represented by a point on the format of **Fig.19**, its damage state was identified as none.

7. LIFELINES

According to a report from the Water Authority in Aqaba there were five breaks in the water-distribution pipelines and breaks in one of the trunk lines (900 mm diameter high-pressure line). The trunk line failed at the locations of some welded joints, which were subject to ground motion. Also one of the main water-supply lines for a factory of fertilizers was broken. There was no damage in the main water reservoirs of the city.

The Aqaba Thermal Power Station which provides forty percent of the electricity needs for Jordan was visited. We were told that technical problems occurred in the electrical transformers in the first and second units during the earthquake causing automatic shutdown in these two units. However electricity was returned during the same day by using standby transformers.

According to the report of the Aqaba Civil Defense Department, the earthquake caused nineteen injuries and no deaths. Most of these injuries occurred while people were rushing out of buildings during the earthquake. No fires occurred during the earthquake. All the bridges escaped structural damage, and the roadways were functional without problems during the earthquake. The three main hospitals continued to work and receive the injured during the earthquake. Aldeeseh medical center was closed because of large cracks and failures which occurred in the building walls. In addition, large cracks and failures occurred in the walls of the municipality building and the building of the Directorate of Education in Aqaba.

8. CONCLUSIONS AND RECOMMENDATIONS

Based on the observations and interpretation of records of the November 22, 1995 Gulf of Aqaba earthquake, the following general conclusions can be made:

1) The damage caused by the Gulf of Aqaba Earthquake of November 22, 1995 is considered minor, despite the recorded high ground acceleration, which generally reached 157 cm/s^2 (0.16 g). Fortunately, the epicenter lies in the sea and its focus lies 15 km trenche in the ground. Consequently, most of the seismic energy was dissipated in unpopulated areas and the damaging effects were limited. Nevertheless, the time of the earthquake in the early morning (before people usually go to work), was the main factor in reducing panic and injuries.
2) Common damage (which appeared in many cases), was due to poor construction practice. Well engineered structures survived the earthquake without any structural damage.
3) Design with stiffer upper setions supported on weakly braced, relatively long columns (which help give room for shops, lobbies, and the like) should be avoided in the traditional architectural design.
4) The damage served to demonstrate once again the importance of tying different parts of the structure together.
5) Hopefully, a useful consequence of the earthquake will be a total revision of Jordan's Code for Loads and Forces, and the addition of "Special Provisions for Seismic Design" to Jordan's Code for Ordinary and Reinforced Concrete. The revision of these codes should be in accordance with modern scientific developments and design concepts.
6) Some evidence was shown to demonstrate that soil conditions and liquefaction influence the destructiveness by which an earthquake hits various types of structures. The existing hotel area in Aqaba on the shoreline may be riskier

for more flexible buildings during major earthquakes. Inland areas with denser alluviums or rock sites should be considered for constructing highrise buildings and hotels.

ACKNOWLEDGMENT: The authors would like to express their thanks to Jordan University of Science and Technology and Hashemite University for supporting the scientific trips which were carried out during the first two weeks after the earthquake.

NOTATION

The following symbols are used in this paper:

A_{col} = total cross-sectional area of columns above base.

A_{cw} = total cross-sectional area of reinforced concrete walls in one horizontal direction at base.

A_{ft} = total floor area above base in a building.

A_{wt} = effective cross-sectional area of walls in a given horizontal direction.

A_{mw} = cross-sectional area of non-reinforced masonry filler walls in one horizontal direction at base.

$A_{ce} = A_{col}/2$ = effective cross-sectional area of columns at base.

CI = column index.

MMI = Modified Mercalli Intensity scale.

S1 = strong motion station located at the basement of Aqaba Hotel building.

S2 = strong motion station located at the basement of Aqaba building

WI = wall index.

REFERENCES

1) Ben-Avraham, Z., Garfunkel, Z., Almagor, G., and Hall J. K. : continental breakup by aleaky transform: The Gulf of Eilat (Aqaba), *J. Science*, Vol.206, pp.214–216, 1979.
2) Quennell, A. M. : The Western Arabia rift system, *Proc. Geological Evolution of the Eastern Mediterranean*, pp.775–788, Geol. Soc. London, England, 1984.
3) El-Isa, Z. and Al-Shanti, A. : Seismicity and tectonics of the Red Sea and western Arabia, *Geophysical Journal*, Vol.97, pp.449–457, 1989.
4) Poirier, J. P. and Taher, M. A. : Historical Seismicity in the Near and middle East, North Africa, and Spain from Arabic documents (VIIth–XVIIIth century), *Bull. Seis. Soc. Am.*, Vol.70, pp.2185–2201, 1980.
5) Ambrasyes, N. N. and Melville, C. P : Evidence for intraplate earthquakes in northwest Saudi Arabia, *Bull. Seis. Soc. Am.*, Vol.79, pp.1279–1281, 1989.
6) El-Isa, Z., Merghelani, M., Bazzari, M. : The Gulf of Aqaba earthquake swarms of 1983 January–April, *Geophys. J. R. Astr. Soc.*, Vol.78. pp.711–722,1984.
7) Alamri, A. M., Schult, R. and Bufe, C. : Seismicity and aeromagnetic features of the Gulf of Aqaba (Eilat) region, *JGR*, Vol.96, pp.20179–20185, 1991.
8) Shapira, A. and Shamir, G. : Seismicity parameters of seismogenic zones in and around Israel, *Inst. Pet. Res. and Geophys.*, Rep. No.Z1/567/79 (109), p.8, 1994.
9) Al-Tarazi, E. : The earthquake of 22 November, 1995 – A maximum intensity distribution map, sub. to *J. of Natural Hazard*, 2000.
10) Bozorgnia,Y., Niazi, M. and Cambell, K. W. : Characteristics of Free-Field Vertical Ground Motion During the Northridge Earthquake, *Earthquake Spectra*, Vol.11, No.4, pp.515–525, 1995.
11) Su, F., Anderson, J. G., Der Ni, S. and Zeng, Y. : Effect of Site Amplification and basic response on Strong Motion in Las Vegas, Nevada, *Earthquake Spectra*, Vol.14, No.2, p.357, 1998.
12) Saffarini, H. S. : Ground Motion Characteristics of the November 1995 Aqaba Earthquake, *Engng. Struct.*, Accepted for Publication.
13) Wakabayashi, M. : *Design of Earthquake-Resistant Buildings*, McGraw-Hill Book Company, New York, USA., 1986.
14) H. J. Degenkolb Associates, Engineers, San Francisco, California : The Superstition Hills Earthquakes, Reprinted with Permission, *ACI Concrete International: Design and Construction*, Vol.10, No.6, pp.62–65, June 1988.
15) Matso, K. : Lessons from Kobe, *ASCE Civil Engineering Magazine*, pp.42–47, April 1995.
16) Osman, A. and Ghobarah, A. : The Aqaba Earthquake of November 22, 1995, Learning from Earthquakes, *EERI Earthquake Report*, 12pp., May 1996.
17) Ghawanmah, Y. H. : Earthquakes Effects on Bilad Ash-Sham Settlements, Studies in the History and Archaeology of Jordan, IV. S. Tell (Editor), Amman, Department of Antiquities, pp.53–59, 1992 (in Arabic).
18) Shiga, T., Shibata, A., Takahashi, T. : Earthquake Damage and Wall Index of Reinforced Concrete Buildings, *Proceedings of the Tohuku District Symposium*, Architectural Institute of Japan, No.12, pp.29–32, Dec.1968 (in Japanese).
19) Hassan, A. F. and Sozen, M. A. : Seismic Vulnerability Assessment of Low-Rise Buildings in Regions with Infrequent Earthquakes, *ACI Structural Journal*, Vol.94, pp.31–39, Jan.–Feb. 1997.

(Received April 7, 2003)