International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics

1991 - Second International Conference on Recent Advances in Geotechnical Earthquake Engineering & Soil Dynamics

10 Mar 1991, 1:00 pm - 3:00 pm

Structural Damage in a Populated Area due to an Active Fault

N. Kalteziotis
Central Laboratory of Public Works, Athens, Greece

N. Sabatakakis
Central Laboratory of Public Works, Athens, Greece

G. Koukis
University of Patras, Greece

H. Zervogiannis
Central Laboratory of Public Works, Athens, Greece

G. Tsiambaos
Central Laboratory of Public Works, Athens, Greece

Recommended Citation

Kalteziotis, N.; Sabatakakis, N.; Koukis, G.; Zervogiannis, H.; and Tsiambaos, G., "Structural Damage in a Populated Area due to an Active Fault" (1991). *International Conferences on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics*. 17.
https://scholarsmine.mst.edu/icrageesd/02icrageesd/session13/17

Proceedings: Second International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, March 11-15, 1991, St. Louis, Missouri, Paper No. LP28

Structural Damage in a Populated Area due to an Active Fault

N. Kalteziotis
Head of Geotechnical Engineering Section, Central Laboratory of Public Works, Athens, Greece
G. Koukis
Associate Professor of Engineering Geology, University of Patras, Greece
G. Tsiambaos
Central Laboratory of Public Works, Athens, Greece
N. Sabatakakis
Central Laboratory of Public Works, Athens, Greece
H. Zervogiannis
Central Laboratory of Public Works, Athens, Greece

SYNOPSIS: The city of Patras was struck in August 1989 by a shallow earthquake of M_S= 4.8 which caused a surface rupture and serious structural damage to several buildings located in a narrow elongated zone. A detailed investigation programme was carried out including geological mapping, drilling of boreholes, in situ and laboratory testing and monitoring of horizontal and vertical movements. It was found that the surface rupture, about 1500 m long, was closely related with the reactivation of a preexisting normal fault. The structural damage of buildings was found to be limited mainly in a narrow zone 50 m wide along the fault and connected with its movements and the seismic intensity.

INTRODUCTION

Patras, the third largest city of Greece located on the Northwestern coast of Peloponnese, was struck on August 31st, 1989 by an earthquake of a small magnitude which caused serious structural damage to new multi-storey and old two-storey buildings in a limited area of the city. The main earthquake of a magnitude M_S = 4.8, with a focal depth of about 1 km, occurred at 21h 29 min 29.7 sec G.M.T on the above date. It was located at 38.16 N, 21.82 E, about 5 km from Patras. The after-shock sequense was almost absent.

This earthquake was the third of a series of shocks manifested in 1989, while this seismic activity continues in 1990 with shocks of about the same magnitude (M_S = 4.5 - 5.2). All the earthquake epicenters are located in the Gulf of Patras within a distance from the city less than 10 km. It must be noted that the structural damage of buildings was observed in a narrow elongated zone, about 1500 m long and 50 m wide, along with a surface rupture related to the reactivation of a normal fault.

In this paper the results of the study of the geological and geotechnical conditions in the area of Patras and the relation of the surface rupture with the buildings damage, are presented and discussed after a detailed investigation which included: (a) geological mapping and tracing of the surface rupture; (b) execution of boreholes, in situ and laboratory testing; (c) description and study of the different geotechnical units; (d) monitoring of horizontal and vertical movements in the vicinity of the rupture; (e) study of the foundation conditions in relation to the structural damage of buildings.

GEOLOGICAL SETTING

The broader area of the city of Patras is emplaced in the Patraikos gulf basin. The basement rocks, which outcrop in the mountainous area eastward to south-eastward of the city, present the features of the Olonos - Pindos geotectonic zone and consist mainly of flysch formations and of thin-bedded limestones and radiolarites.

The plio-pleistocene sediments of the basin, exhibiting gentle morphology (elevation up to 200 m) and dipping to the south (10°-30°) are mostly covered by old quaternary and recent alluvial deposits. Two horizons can be distinguished in these sediments, namely a lower fine-grained with a thickness greater than 150 m and an upper coarse-grained one usually of 50 m thick (Rozos, 1989; Koukis and Rozos, 1990).

In the narrow area of the city, which has a medium to low relief, the plio-pleistocene sediments developed consist of dark-grey to bluish-grey marls, silty clays and sandy silts in the lower horizons, while in the upper ones alternations of clays, sands and gravels, conglomerates and clayey silts predominate. According to the data of the boreholes carried out, the total thickness of the plio-pleistocene sequence exceeds the 300 m and in the coastal zone is covered by younger quaternary deposits.

Regarding the fault tectonics two main groups of normal faults have affected the plio-pleistocene deposits, due to the extensional phase of stresses acting in the area since the period of upper Neogene. The mean srtike of these two groups of faults is NE-SW and NW-SE respectively (Mettos et al., 1987; Doutsos et al., 1987; Rozos, 1989).

The high seismicity of the area is closely related to the above mentioned fault tectonics. Frequent shallow and usually of high magnitude earthquakes are recorded in the Gulf of Patras (Drakopoulos, et al., 1987) which cause serious problems in the broader area (damage in buildings and technical works, landslides, rockfalls, flows, liquefactions etc.).

SURFACE RUPTURE

As mentioned previously, the most important feature connected with the seismic activity is the longitudinal surface rupture. This was traced after a detailed mapping at a scale of 1:5000, Figure 1.

The surface rupture consists of a major branch having a mean strike N 70°E, and locally of some minor subparallel cracks striking N 60°-75°E. The total length of the rupture is more than 1500 m since it cuts, towards the West, the coast of the Gulf of Patras and probably continues into the sea. Following the fault trace from the coast to the East, it has affected the pavement of the national road from Patras to Olympia (Figure 2), runs parallel to a section of the rigth old bank of Diakoniaris creek for about 500 m and continues into the residential area where the major damage of buildings has been observed.

The aperture of the main rupture as well as its vertical displacement was progressively increased since the data of the main earthquake. As it was measured few days after the shock the maximum aperture of the rupture was 1 cm and the vertical displacement (downthrow of the south side) less than 5 mm. Few months later, these were increased to 3 cm and 2 cm respectively.

Concerning the surface rupture mechanism, the linear appearance of its trace and the low topographic relief of the region exclude its connection to landslides and in some degree to subsidence phenomena, which are usually associated with the earthquakes. Thus, in order to study the nature of the surface rupture and its probable relation with geological structures, a series of recent and old stereopairs of airphotos (for the period 1945 - 1988) were examined. From this detailed interpretation a normal fault was revealed with a prevailing scarp coinciding in general with the recent surface rupture. This scarp was recognised only in the old airphotos (years 1945 and 1960), whereas later this was covered by earthfill materials due to land reclamation and construction of one to two-storey and later multistorey buildings.

This normal fault has an observed length of more than 3 km, one of its edges being at the coast and the other to the mountains. It strikes N 70°E and is parallel to one of the main groups of faults affecting the plio-pleistocene deposits in the broader area of Patras.

The direct relation between this normal fault and the seismic activity is now under investigation and towards this aim a special study is undertaken to record probable epicenters of shallow earth quakes with a low magnitude (M_s=2.5 to 3.5) along the trace of it. Furthermore, the continuous monitoring of the vertical and horizontal displacements will permit the detection of the seismic movements of the fault.

GEOTECHNICAL INVESTIGATION

In order to study the geological-geotechnical conditions in the area affected by the surface rupture a detailed investigation program was carried out (Figure 1) including the execution of 16 boreholes, 24 cone penetration tests (CPT), 1 cros hole test (CHT), Standard penetration tests (SPT and laboratory testing. Based on the results of the above investigations the following grouping of the geotechnical units was made (from top to bottom):

Unit 1:

Brownish-yellow to brownish-grey, medium to stif sandy clays with some gravels in places and pock ts of sandy silts or silty sands. This covers the major part of the studied area, its total th ckness is up to about 25 m, and is thining towards the North. According to the grain size distribution curves and the plasticity chart (Figure 3) the members of this unit are mainly classified either as clays of low plasticity, CL, (W_L= 18.8 - 43.7 and I_P= 5.7 - 29.7) or as silts or silty-clays (ML, ML-CL). This unit could be further subdivided into two sub-units, according to the strength of its members as it was determi ned by in-situ and laboratory testing.

Sub-unit 1a: mainly clays of medium strength (mean unconfined compressive strength q_u=60 kPa, mean value of N_{SPT}=5 blows/30 cm penetration, and mean cone resistance q_c=1000 kPa).

Sub-unit 1b: mainly stiff, overconsolidated clay (mean unconfined compressive strength q_u=300 kPa, mean value of N_{SPT}=23 blows/30 cm penetration, and mean cone resistance q_u=2000 kPa).

Unit 2:

Brownish-red to brownish-grey sandy clays with gravels, brownish-grey silts or sands and locally clayey sands and gravels. It constitutes a mixec phase of alternating layers in a vertical and horizontal direction with a total thickness ranginc from about 45 to 65 m. A further subdivision of this unit in three sub-units can be made according to the nature and physical-mechanical characteristics of the material as follows:

Sub-unit 2a: brownish-red to brownish-grey, medium to very stiff, sandy clays, with some gravels and pockets of sand and silt. These deposits are mainly classified as clays of low to high plasticity, CL or CH (W_L=16.4 - 51.6 and I_P=4.4 - 34.0) and silty clays or clayey silts (CL, ML). In Figure 3 the envelope of grain size distribution curves and the plasticity chart are given. The mean value of their unconfined compressive strength, q_u, is 200 kPa, while that of N_{SPT}=36 blows/30 cm penetration.

Sub-unit 2b: mainly clayey sands and gravels with cobbles, of a thickness up to 15 m.

Sub-unit 2c: grey to brownish-grey clays with thin intercalations of sands and silts, of a total thickness up to 17 m. They are classified as clays of low plasticity, CL, (W_L=17.3 - 43.8, I_P=5.3 - 27.5) and as clayey silts (CL-ML). The mean value of the unconfined compressive strength is 136 kPa and that of N_{SPT}= 59 blows/30 cm penetration.

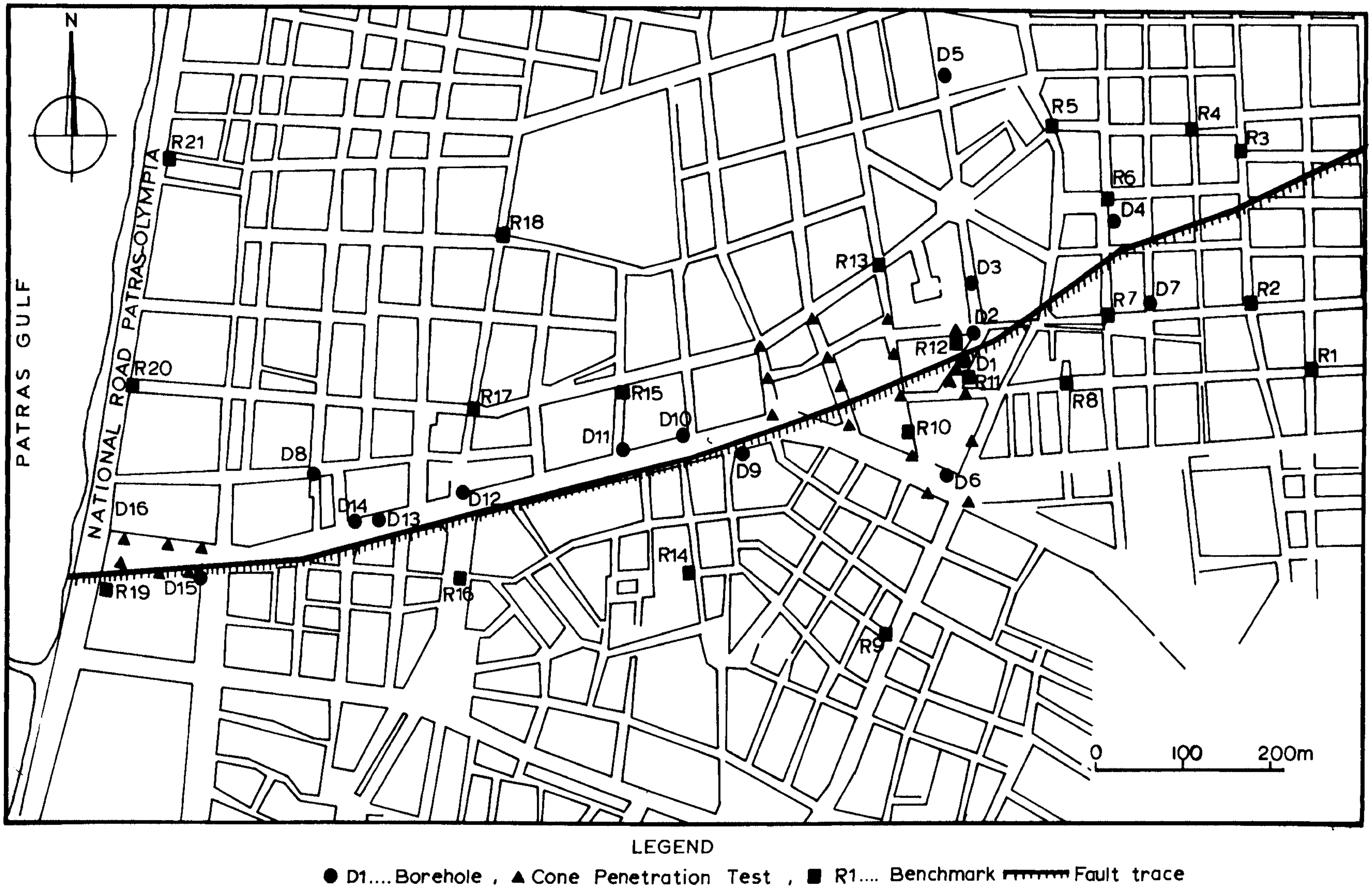

Fig.1. Documentation map of the area in the city of Patras affected by the earthquake of August 1989

Fig. 2. Surface rupture traced on the pavement of Patras-Olympia motorway

Unit 3:

Clayey sands and gravels and medium to well cemented conglomerates. This is locally developed at a depth of 50 to 85 m and covers the marly bedrock whereas its thickness varies from 9 to 15 m.

Unit 4:

Bluish-grey marls. It constitutes the geologica bedrock of the studied area and it was found during drilling at a depth of 60 to 95 m. Its thickness exceeds 250 m, as it was confirmed by drilling a borehole with an approximate total length of 330 m. These marls present a calcium carbonate content varying from about 15 to 50% and are classified as clayey or normal marls. According to their grain size distribution and plasticity (Figure 3), they are classified as clays of low plasticity, CL, (W_L= 26.7 - 47.0 and I_p= 9.6 - 27.0). The uncinfined compressive strength, q_u, varies from 190 to 250 kPa, they present a natural water content W = 25 - 27%, whereas the values of N_{SPT} for 30 cm penetration ranges from 60 to 90.

The geological section shown in Figure 4 illustrates the sequence of the geotechnical units described above and the normal fault which has caused the relative displacement of the layers (the thro is up to about 10 metres) and the recent surface rupture. A typical geotechnical profile which includes only the upper units 1a, 1b and 2a, is shown in Figure 5. In this the results of SPT, CPT and Cross-Hole testing up to a depth of about 40 m are shown.

STRUCTURAL DAMAGE

Faults in seismic areas are usually a predominant factor for the safety of engineering constructions. They may cause not only various destructive stress waves through their large release of strain energy but also induce ground movements and de formations in large scale which may cause serious structural damage.

It is well known that during earthquakes the in-

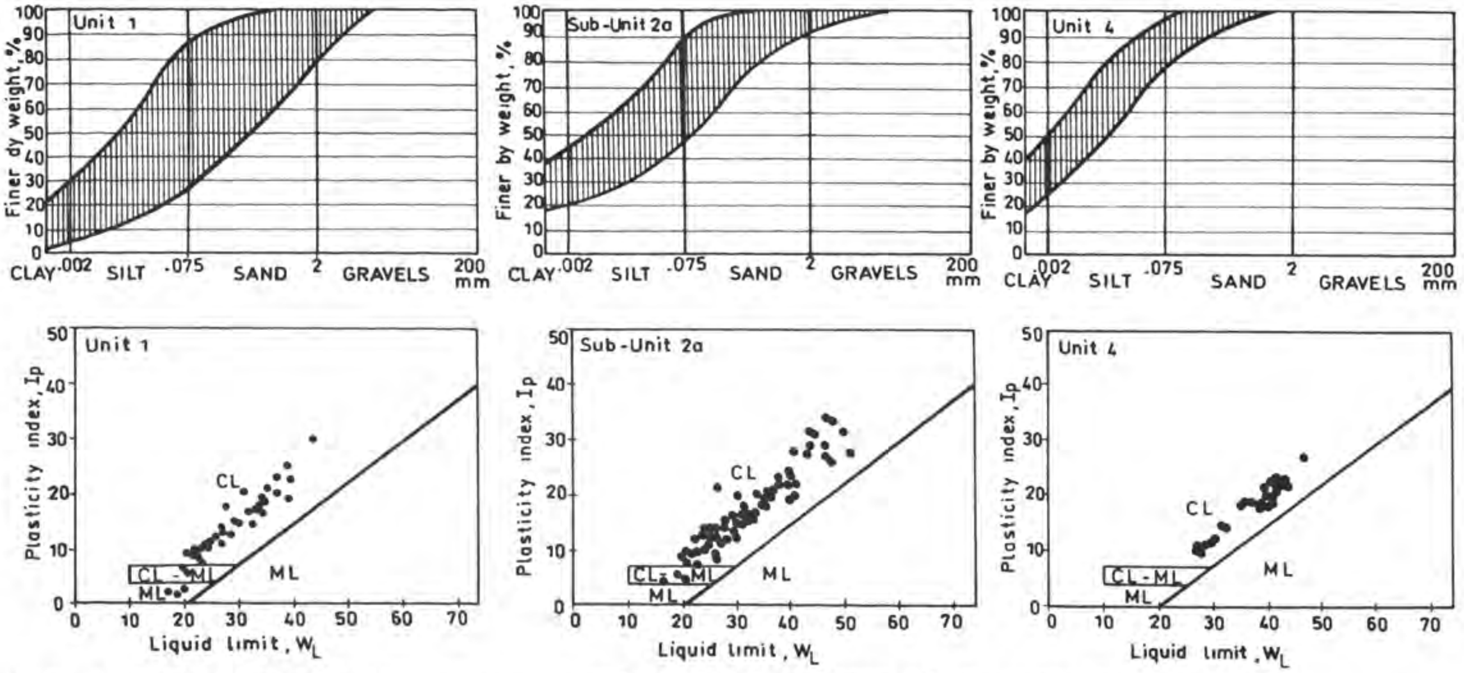

Fig. 3. Grain size distribution curves and plasticity charts of the geotechnical units

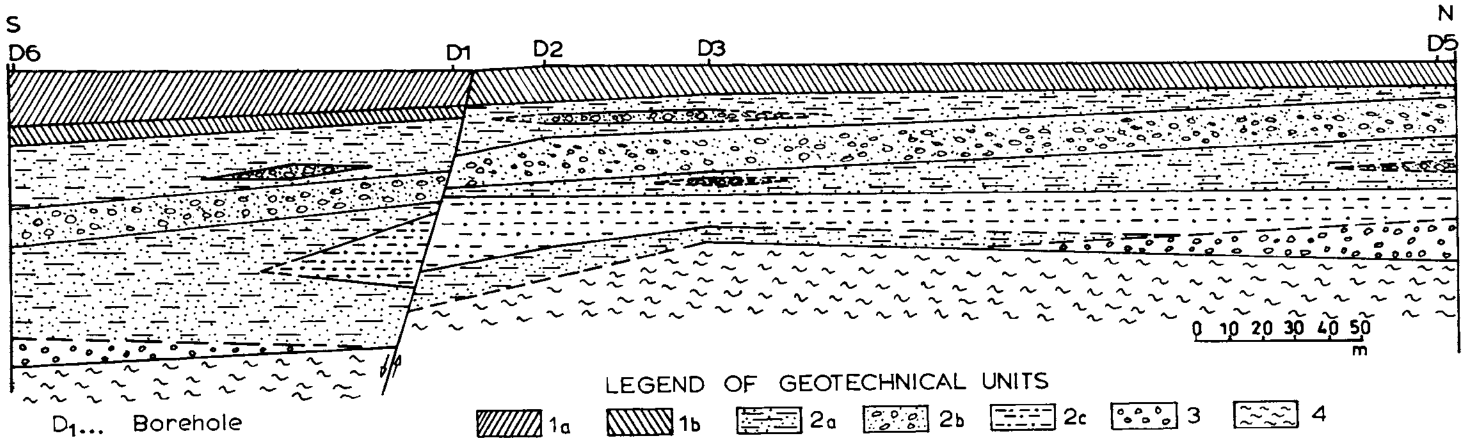

Fig. 4. Geological section through the boreholes D6, D1, D2, D3 and D5

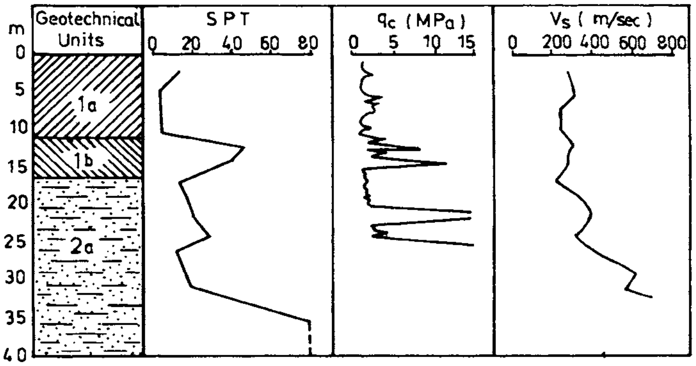

Fig. 5. Typical geotechnical profile of the upper geotechnical units

fluence of reactivated faults on damage of buildings and other technical works is still a matter of ongoing research. Thus, several international seismic regulations include paragraphs with restrictions concerning the site limitations for seismic design:

- The ACT-3-06, 1984 regulations anticipate that no building assigned to provide the highest level of design performance criteria (category D) shall be sited in areas where the potential for an active fault to cause rupture of the ground surface is high.
- The French regulations PS.86 are more strict specifying that no building shall be sited within a zone of 50 metres from the fault trace while for building of the highest level of design performance this zone is extended to 100 metres.
  The above mentioned earthquake in Patras has provide some evidence of the close relation of the fault with building damage.

The main part of the rupture observed was extended in free ground, causing damage in road pavements and other superficials works, (i.e. hydraulic connection tubes), whereas some part was extended to a populated area of the city of Patras and caused damage of buildings.

It is important to note that the dislocation and tensile cracks observed in the top soil immediately after the main shock continued to increase with time. This is well illustrated in Figures 6a and 6b which show an athletic playground with a flexible asphaltic surface. A few days after the main shock the horizontal displacement was about 1 cm and the vertical one less than 5 mm, (Figure 6a), whereas four mounths later the displacements were increased to about 3 cm and 2 cm respectively (Figure 6b).

The observed damage of buildings caused by faulting rupture was in static manner rather than dynamic and because of the low intensity of the earthquake far from disastrous. Two kinds of damage were observed concerning single storey and multi-storey buildings.

The damage of buildings was closely related with the surface rupture, whereas the discontinuity of the ground resulted in an unavoidable break in certain parts of the structures along the fault trace. Such damage of a two-storey building is shown in Figure 7, where the broad rupture in front of the building has caused the rupture of the walls. In all these cases the buildings situated directly on the surface rupture had increased the rigidity of the local ground and the ruptures are much smaller than these on the free ground surface. This effect has also been pointed out by Wang et al. (1981).

As shown in Figure 8a, the surface rupture crossed the interface of two six-storey buildings which suffered severe damage, (site of borehole D1), and caused relative movement in all three directions of only one of the two buildings (Figure 8b). This building was situated to the south side of the fault (downthrow region) whereas the other building was situated on the immovable north side, (upthrow region).

MONITORING OF MOVEMENTS

The monitoring of vertical and horizontal movements in the area of the city of Patras, which has been struck most severely by the earthquake, has been made with geodetic methods (Stathas et al., 1990).

(a) (b)

Fig. 6. Increase of the surface rupture aperture with time in an athletic playground

Fig. 7. Structural damage of a two-storey building located on the surface rupture

For measurement of the horizontal movements in the vicinity of the two multi-storey buildings mentioned above a microtriangulation network (both angles and distances) was used. For vertical movements determination two spirit levelling nets were used. The first net, which was in the vicinity of the two buildings was used to monitor absolute and relative displacements (settlements) The second net was in a zone on either side of the fault and it was used to monitor relative vertical displacements along the fault (i.e. the upthrow and the downthrow). To measure the angles, a WILD T2 Theodolite, with direct reading to 0.1 mgon (1 cc) was used, whereas for the distances a WILD D1 1000 EDM with an accurary of ±5 mm ±5 ppm was used. Levelling was undertaken with a WILD NA2 level.

The levelling net in the zone on either side of the fault utilised 21 Bench Marks (Figure 1). Eleven of the Bench Marks were in the upthrow region and ten in the downthrow. The net was 1500 m long with an average width of approximately 400 m. Measurement was undertaken in two phases, the first from February 10 to 14, 1990 and the second one from April 1 to 5, 1990. Reduction and adjustment of the net was made by the Least Squares Method using a computer. Comparison between the two phases assuming a significance level of 99% gave the following settlements:

Bench Mark	Settlement (mm)
R 1	6
R 2	4
R 7	6
R 8	15
R 9	22
R10	16
R11	14
R14	19
R16	14
R19	12

The rest of Bench Marks showed no measurable settlements. Therefore , there are settlements only in the downthrow region of the fault. For example, Bench Mark R12 (adjacent to one or the two

(b)

Fig. 8. Rupture crossing the interface of two six-storey buildings and the relative displacement

multi-storey buildings), showed no settlement between the two phases, while Bench Mark R11 (on the other building) which is downhill of the fault showed 14 mm settlement. The greatest settlement found was at Bench Mark R9 (22 mm).

The levelling net for monitoring the vertical movements around the two mentioned buildings comprises the three Bench Marks (R10, R11, R12) and eigth reference points of the microtriangulation network (Stations 1-8).

There have been five phases of measurement. The reduction and adjustment of the net has been made by the Least Squares Method using a computer. Bench Mark R12 has been assumed to be the stable reference point with a level of 17.012 m. This elevation was determined by reduction and adjustment of the initial level survey of the net along the fault. Comparison between the five phases and with a significance level of 99% generated the following total settlements: for Station 4:16 mm, for Station 5:25 mm, for Station 6:19 mm, for Station 7:18 mm, for Bench Mark R11: 20 mm and for Bench Mark R10: 24 mm; all of these points are in the downthrow region of the fault.

The microtriangulation network for the monitoring of horizontal movements in the vicinity of the two buildings comprises eight reference points on the ground (Stations 1-8) and two reference points (Stations 9 and 10) on the roof of each building. Measurements have been made in three phases; March 1 - 4, March 20 - 24 and April 1 - 5, 1990.

In parallel with the measurements for the microtriangulation network, eight control points were installed i.e. four points on each building (two on first floor and two on the fourth), as can be seen in Figure 9. The purpose of these control points was firstly to monitor the differential horizontal movements between the load-bearing elements of each building and secondly to determine the relative movements berween the two buildings. These control points are referenced to stations 3, 4 and 5 which have been considered as stable. Comparison between the three phases of both the microtriangulation and control points networks defined the following horizontal displacements (with a significance level of 99%): (a) Between the first and second phases of the mocrotriangulation network there were horizontal displacements of 9 mm (Station 7), 5mm (Station 8) and 14 mm (Station 9); (b) Between the first and second phases for the control points there were horizontal displacements of 9 mm (point 1), 10 mm (point 2), 9 mm (point 3) and 4 mm (point 8) and (c) Between the first and third phases there was no displacement of the reference points of the microtriangulation network while during this period the control points were displaced by 9 mm (point 1), 11 mm (point 2), 6 mm (point 3), 5mm (point 7) and 7 mm (point 8).

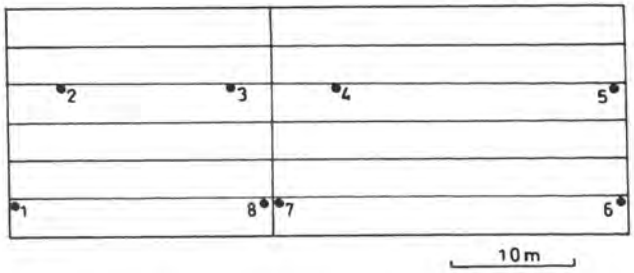

Fig. 9. Face of the two six-storey buildings with control points

In addition to the above network witness marks have been installed on buildings and roads in the area under investigation to provide direct measurement of movement across openings, with the following results:

- The measurements on the two buildings indicated horizontal displacements of 10 mm at the ground floor and 17 mm at fourth floor, in the period February to May 1990.
- Witness marks in the pavement of the Patras to Olympia motorway showed a horizontal displacement of 6 mm over the period March 1990 to May 1990.
- Between January and May 1990 a horizontal displacement of 5 mm was recorded in the pavement of a street close to the borehole D7.

CONCLUSIONS

- The earthquake of August 1989, in the city of Patras, through of a low magnitude (M_s= 4.8), caused severe structural damage of buildings and other technical works.
- This earthquakes also resulted in a surface rupture which is closely related to an old normal fault.
- The structural damage was concetrated only in a norrow zone along this fault. This observation validates existing regulations which require that structures nearby active faults need special consideration.

REFERENCES

ACT-3-06, (1984), "Tentative provisions for the development of Seismic Regulations of Buildings, Second Printing, 242 p.

Drakopoulos, J., Makropoulos, C., Laoutsakis, J., and A. Tselentis, (1987), "Seismological study of Rio-Antirio region", unpublished report (3 Volumes), Geodynamic Institute of Athens University (in Greek).

Doutsos, T., Kontopoulos, N., and D. Frydas, (1987), "Neotectonic evolution of northwestern-continental Greece", Geologische Rundschau 76/2, 433-450, Stuttgart.

Koukis, G., and D. Rozos, (1990), "Geotechnical properties of the Neogene sediments in the NW Peloponnesus, Greece. Proc. International Congress IAEG, Amsterdam, Vol. 1, 405-421.

Mettos, A., Rondoyanni, Th., and J. Papadakis, (1987), "Geological study of the Rio-Antirrio region", unpublished report, Institute of Geological and Mining Research (in Greek).

PS.86, Regles Parasismiques, (1986), "Regles relatives aux ouvrages a realiser dans les regions sujettes aux seismes", Document Technique unifie, 107 p.

Rozos, D. (1989), "Engineering geological conditions in the Achaia province. Geomechanical characteristics of the plio-pleistocene sediments", unpublished Ph. D. Thesis, University of Patras, 453 p.

Stathas, D., Georgopoulos G., Bithas, A., and D. Pournaras, (1990), "Monitoring the movements o "Diakoniaris" fault in Patras", unpublished report, Technical University of Athens, 32 p. (in Greek).

Wang, Z.Q., Zhao, S.T., and Z.L., Huang, (1981), "Mechanism of surface faulting and its seismic effect", Proc. International Conference on recent advances in Geotechnical Earthquake Engineering and Soil Dynamics, University of Missouri-Rolla, Vol. I, 499-504.