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COMPARISON OF DAMAGE DUE TO TWO RECENT EARTHQUAKES SAN SALVADOR AND KALAMATA (GREECE)

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SUMMARY

This paper presents a brief description of the effects of two recent medium size earthquakes, namely Kalamata (Greece), 13 September 1986 and San Salvador (El Salvador), 10 October 1986. This covers seismological, geotechnical and structural aspects, together with comparisons where appropriate. General conclusions pertinent to earthquake-resistant design are drawn.

INTRODUCTION

Inspite of the advances made in dynamic testing methods and equipment, field observations of earthquake damage remain the only technique of verifying earthquake resistance which takes into account all salient effects, such as soil-structure interaction, multiple support excitation with spatial variability of motion, scale effects etc. Furthermore, unlike large earthquakes of magnitude 7.5 or more, medium-size earthquakes are a common occurrence in many parts of the world. The destruction potential of such events has been demonstrated by the Skopje (1963), Barce (1963), Agadir (1960) and Managua (1972) earthquakes, for example. It follows that studying such events, their effects and means of damage reduction in the future is very important.

The Kalamata (Greece) earthquake of 13 September 1986 and that of San Salvador (El Salvador) on 10 October 1986 are examples of medium size events striking very close to densely populated areas. Two reconnaissance missions comprising two engineers each were despatched to the affected areas shortly after the earthquakes, and observations were reported (Refs 1,2,3,4). In the following, a brief description of the effects of the two earthquakes is given together with comparison between these effects, where appropriate. Conclusions derived from damage assessment in both affected areas are also presented, based on the authors' observations and those of other researchers (Refs 5,6).

SEISMOLOGICAL AND GEOTECHNICAL OBSERVATIONS

Table 1 shows time, duration, magnitude and maximum recorded accelerations for the two earthquakes and a major aftershock. It is interesting to note that both events had the epicentre located very close to densely populated areas and with shallow focal depths between 2 to 7 Km, hence the damage inflicted on buildings in certain parts of the cities was very severe.

Table 1 Earthquake Characteristics

	Date (Local Time)	S.M Duration	Magnitude Ms	Max Acceleration (g) Horizontal	 Vertical
KALAMATA					
Main shock	13 Sep 86 (20:24)	6 seconds	5.9	0.27-0.30	0.18-0.38
After shock	15 Sep 86 (14:41)	3 seconds	4.6	0.23-0.25	0.08-0.13
SAN SALVADOR					
Main shock	10.Oct 86 (11:49)	6 seconds	5.4	0.22-0.69	0.14-0.45

The Kalamata earthquake was not associated with the active Hellenic arc zone, but was rather due to local faulting, probably in an area extending from the east side in a north-east direction. However, it is noteworthy that, in the authors' opinion, the observed ground cracking and minor landslides east of the Town are not a manifestation of the active fault, but are secondary effects of shaking. In the case of San Salvador, the earthquake was not directly associated with the Middle American Trench, where the Cocos Plate is subducted below the Caribbean Plate, but was related to the volcanic chain that extends through most of Central America. It is known that the metropolitan area of San Salvador is crossed by many local faults of between 2 and 10 km long, but the observed ground cracking was most probably a secondary effect and not a surface manifestation of a fault break. The numerous small landslides in San Salvador were associated with very steep slopes, and were not directly linked to the faulting.

Damage distribution in Kalamata did not follow local geology or soil conditions. Whereas the south-western part of the Town was founded on recent alluvial deposits, many buildings survived unscathed. On the other hand, cases of total collapse were noted in the eastern part and in villages to the north-east which were located on firm ground. In San Salvador, damage seemed to be greater on the east side of the city, where the deposits of volcanic ash are thicker, and the ground motions recorded were stronger. However, any attempt to draw a map of damage distribution would primarily have shown the distribution of quality of construction rather than of foundation condition. This observation reflects the effect of the variability of building techniques and materials, and highlights the difficulties associated with intensity assessment based on structural damage.

There was no evidence of foundation failure or damage due to relative movements of isolated footings in Kalamata, whereas in San Salvador only one case was observed, where a building had been founded on poorly compacted fills. In Kalamata no liquefaction was observed, and this is attributed to the low level of water table and the small number of load cycles to which the soil was subjected. In

San Salvador, where the water table is generally at a depth of more than 80m, only superficial liquefaction was observed in one location where the ground was saturated due to a blocked drain.

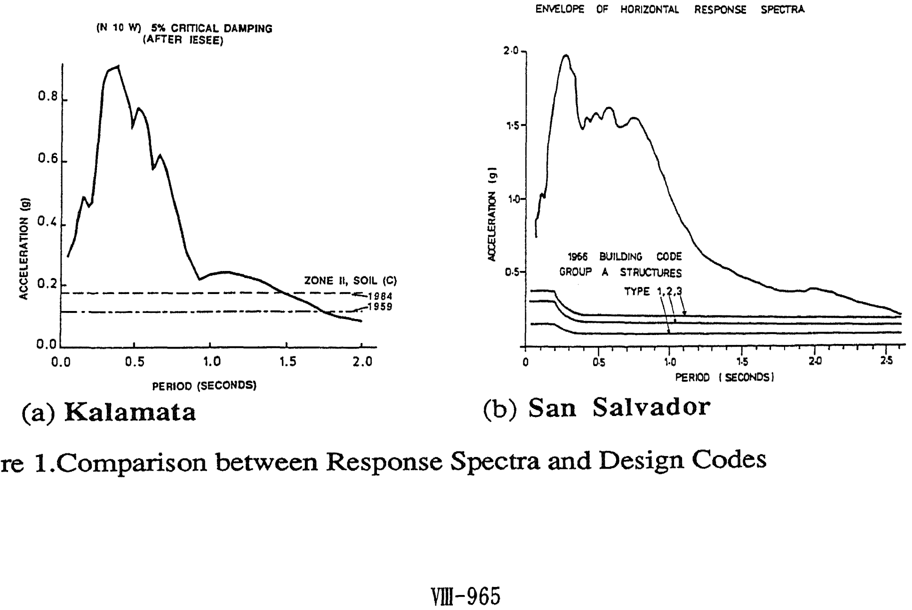
STRUCTURAL OBSERVATIONS

Description of Structures Engineered buildings in both areas were mostly reinforced concrete frame structures with brick or block infill panels of 2 to 6 stories high. The concept of soft storey was used frequently, by having either an open plan or a higher than usual ground floor. A special feature in Kalamata was that reinforced concrete slabs were invariably heavy. Very few steel structures existed in Kalamata, and these sustained very little damage. The northern part, which is the old Town, is mainly brick, block and stone wall bearing construction. Contrary to observations from the Greek earthquake, some masonry buildings in San Salvador were reinforced by steel bars.

In neither of the areas affected by these two earthquakes were there any major bridges, dams or large civil engineering works, although in San Salvador there was a large number of industrial complexes, several of which suffered heavy damage.

Traditional buildings in Kalamata which spanned several centuries in age made use of a wide variety of construction materials, such as stone, adobe, clay bricks and hollow blocks. Mortars used varied between cement or lime-based to mud. The roofs were mostly of timber joists covered with clay or slate tiles. More recent mixed masonry and reinforced concrete construction was often observed. On the other hand traditional buildings in San Salvador were made from bahareque, which comprises timber verticals and bamboo horizontals infilled with mud and covered by a lime plaster. This form of construction generally offers good seismic resistance, but this is greatly reduced by decay of untreated timber in the aggressive tropical climate. In the poorest zones, brickwork, timber and corrugated iron were also used.

Code provisions Code provisions for earthquake-resistant design were first issued in Greece in 1958, and were updated in 1984. The code does not take into account the dynamic characteristics of the building; the base shear coefficient is a function of zone and soil condition only. A code for aseismic construction in El Salvador was introduced in 1946, but was not enforced. Another code was introduced soon after the 1965 earthquake, but it also is reported not to have been implemented. This code specified a base shear coefficient which unlike the Greek code was dependent on zone and dynamic characteristics, but not soil type, as shown in Figure 1.a and 1.b.



(a) **Kalamata** (b) **San Salvador**

Figure 1.Comparison between Response Spectra and Design Codes

Observed Damage Only a small percentage of reinforced concrete structures in Kalamata were heavily damaged or collapsed. In San Salvador, about 75 engineered structures of three or more stories suffered structural damage, with a few cases of total collapse. In the majority of cases, columns showed shear cracking patterns, while beams were very rarely cracked. In many cases, stiff columns failed while more flexible ones survived, as observed in the schools complex in the eastern part of Kalamata. Column failure was often away from beam-column connections, while in some cases, sliding of the beam on the column was observed. Several cases of collapse can be attributed to brittle failure of short reinforced concrete columns.

Severe non-structural damage was observed in a large percentage of buildings, even where very little structural damage was sustained, as was the case at the telecommunications company, ANTEL, and the Constancia Brewery, in San Salvador. The observed patterns of behaviour indicate basic design shortcomings as well as poor construction practices, as discussed hereafter.

In Kalamata, the Greek organization for seismic protection (O.A.S.P) has undertaken structural inspections of all buildings in the affected area immediately after the mainshock. The damage distribution within the three categories of buildings as reported by O.A.S.P. are shown in Figure 2 below. As can be seen, a large number of traditional buildings suffered severe damage, thus raising very substantially the cost of repair and reconstruction. The modes of failure covered a very wide range, such as out-of-plane panel failure, total collapse of roofs, severe cracking of piers and separation of walls at corners. A list of likely causes of this high degree of damage is given below. The amount of damage in San Salvador was much higher since the population density was higher in the affected area. The first estimates were that 23,000 dwellings have been destroyed and 30,000 were badly damaged and to the knowledge of the authors no detailed survey of the damage has been reported.

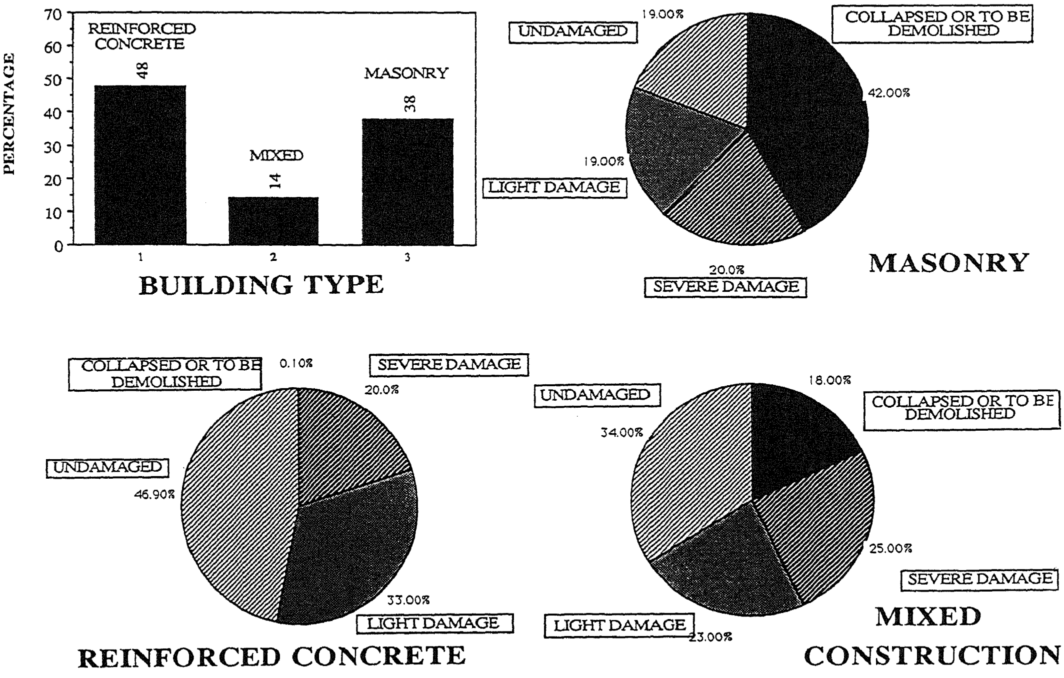


Figure 2: Damage statistics for Kalamata as reported by the Greek organization for seismic protection (O.A.S.P.).

Causes of Structural and Non-Structural Damage In both events design errors and unacceptable construction practices were the underlying causes of the heavy damage sustained by engineered structures. The main design errors observed were: strong beam-weak column design, intentional and accidental short column with inadequate ductility, reinforced concrete walls with low shear capacity, soft storey design, highly irregular plan layout with asymmetric mass and stiffness distributions, framing action provided in one direction only and high storey drifts leading to severe non-structural damage.

On the construction side, the main observations were: poor detailing of construction joints in terms of concrete and reinforcement continuity, lack of stirrups at critical sections of load-bearing members leading to very low confinement, inadequate cover causing rusting of reinforcing bars, use of inferior concrete and poor mixing and placing practice. In the case of San Salvador, another contributing factor to the damage sustained by engineered structures was the inadequate repairs applied after the earthquake of 3 May 1965.

In the case of traditional buildings, in Kalamata, the main causes of damage were: aging and inadequate maintenance, use of poor mortars, inadequate support for roofs and lack of connections between adjacent walls, insufficient strengthening of openings, use of highly irregular plans and asymmetric layout. In San Salvador, damage to traditional buildings was mainly due to aging. The extensive damage to housing in the poorer zones of the city was in the large part due to the fact that these dwellings were located on the steep slopes on the outskirts of the city and on the slopes of ravines, causing a serious stability problem.

In addition to the above deficiencies, in both cases damage was aggravated by the frequency content of the earthquakes, as shown in Figure 1.a and 1.b, where the earthquake 5% damping elastic response spectra are compared to the relevant design spectra. The horizontal component exhibited high peaks corresponding to a period of 0.2 to 0.6 seconds, coincident with the natural period of 2 to 6 storey buildings. Furthermore, the vertical component peaked around periods of 0.08 to 0.2 seconds, close to the period of axial vibration of some buildings. This vertical component in some records exhibited peak acceleration of about 80% of the peak horizontal value.

GENERAL CONCLUSIONS

In the following, observations from the two earthquakes are used to derive some general conclusions that may be of interest to engineers involved in earthquake-resistant design and reconnaissance missions.

- Earthquake-resistant design regulations should take into account, not only large earthquakes caused by intra-plate tectonic activity, but also events of a local nature originating from previously unidentified inter-plate faults.

- In contradiction with code recommendation of taking the vertical motion as 66% of the horizontal input, peak vertical accelerations for near shallow earthquakes may be more than 80% of the corresponding horizontal value.

- The concept of soft storey imposes very high curvature ductility demand on column to beam connections, which if not supplied can cause collapse.

- In the presence of heavy slabs, it is difficult, yet of paramount importance, to achieve strong column-weak beam design. Column failure may cause very high storey drifts, leading to heavy non-structural damage and collapse.

- Lateral force resisting systems should be provided in both orthogonal directions. In the presence of a clear weak axis, the building will tend to shift sideways, causing severe damage to column heads.

- Whereas asymmetry, either intentional or accidental, is often unavoidable, the provision of shear walls with well confined edge members in two directions increases substantially the torsional resistance and protects the columns from shear (torsional-induced) failure.

- Storey drift control is essential for avoiding severe non-structural damage that can increase the cost of repair very substantially. This can be achieved by providing reinforced concrete structural walls.

- Building masonry structures as a monolithic unit with roofs tied to wall and strong corners is essential for adequate behaviour under earthquake conditions.

- Repair and strengthening to structures damaged at their lower levels must be carried up throughout the height of the building in order to avoid damage to higher levels in subsequent earthquakes.

- As demonstrated in Figures 1.a and 1.b, the correlation between design base shear coefficients and earthquake resistance is very weak. Ductility and energy absorption capacity may be much more relevant. It is hence important to note that increasing base shear coefficients does not necessarily lead to higher earthquake resistance.

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REFERENCES

1. Elnashai A.S. and Pilakoutas K., "The Kalamata (Greece) Earthquake of 13 September 1986", ESEE Report 86-9, Civil Engineering Department, Imperial College of Science and Technology, London, (1986)
2. Elnashai A.S., Pilakoutas K.,Ambraseys N.N and Lefas L.D., "Lessons learned from the Kalamata (Greece) Earthquake of 13 September 1986", European Journal of Earthquake Engineering, (1987)
3. Ledbetter S.R. and Bommer J.J., "The San Salvador Earthquake of 10th October 1986", A field mission report by EEFIT, SECED, The Institution of Civil Engineers, London, (1987)
4. Bommer J.J. and Ledbetter S., "The San Salvador Earthquake of 10th October 1986", In Disasters, Vol. 2,No.2, The Journal of the Relief and Development Institute, London, (1987) pp. 83-95
5. INTERTECT, "Earthquake damage assessment and recovery issues in Kalamata region, Peloponnese, Greece", Prepared for the office of U.S. Foreign Disaster Assistance, Agency for International Development, Washington D.C., (1987)
6. Anagnostopoulos S., Theodoulides N., Lekides B.A. and Margaris B.N, "The Kalamata Earthquakes of September 1986, IESEE: 86-05, Institute of Engineering Seismology and Earthquake Engineering, Salonica, Greece, (1986), 103 pp, {In Greek}