ANALYSIS OF R/C STRUCTURES DAMAGED BY THE 1980 SOUTH ITALY EARTHQUAKE

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SUMMARY

Two reinforced concrete(R/C) structures were picked out from many damaged structures by the 1980 South Italy earthquake and they were investigated in detail. One structure was a three story R/C apartment house in Lioni. The other was a R/C water tank of about 18m height in Conza della Campania. Bi-directional non-linear response analysis of the structures to the recorded accelerations was carried out. The state of damage to each structure was explained well by the analysis using STURNO EW, NS accelerations.

INTRODUCTION

On November 23 in 1980, Southern Italy was struck by a strong earthquake and suffered severe damages. To examine in detail the state of damage to the structure by an earthquake should lead to more reasonable aseismic design method. Two damaged R/C structures were investigated particularly on the scene and analyzed the response of them to the recorded accelerations. The structures were modelled to bi-directional lumped mass vibration system. Non-linear bi-directional restoring force model was formulated using the concept of plastic potential.

THE STRUCTURES AND THE DAMAGES

A three story R/C apartment house in Lioni was heavily damaged. South and east elevations of the house are shown in Fig. 1. Whole view and the situation of 2nd story after the earthquake are shown in Photos. 1 and 2. The house was under construction and was just before completion. Garrets were made between the 4th floor and the roof. Horizontal section of the 2nd story is shown in Fig. 2. The sections of 1st and 3rd stories were similar as that of the 2nd story. There were three types of columns as shown in Fig. 3, i.e. 13 columns with rectangular cross section, 4 columns square section and 2 columns polygonal section, in each story. Slabs and beams between 1st story and 2nd story is shown in Fig. 4, and notations of column lines are indicated. Details of walls are shown in Fig. 6. The typical joist slab constitution used in this region is shown in Fig. 6, and similar one was used in this house. The damage to the house concentrated in the 2nd story. Photos. 3 and 4 show the state of damage occurred at the top of the column in the 2nd story. As shown in Phto. 4, the concrete crushed and the cover concrete was spalled and longitudinal reinfocements buckled.

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A R/C water tank structure in Conza della Campania was damaged, too. The outline of the structure and that of the damage are shown in Figs. 8 and 9, and Photos. 5 and 6.

All the dimensions in Figs. 2, 3, 5, 6 and 8 were measured on the spot or were deduced from photographs. They are, consequently, not exact but rough values.

ANALYSIS

About the 1980 South Italy earthquake, many accelerations were recorded. Recorded accelerations are offered by "Commissione CNEN-ENEL, Rome, Italy". The accelerations, STURNO, EW, NS, used in this study were offered by the committee and zero base-line correction was carried out by the similar method as Ref. 1. Accelerations STURNO EW, NS for the response analysis are shown in Fig. 9.

The apartment house in Lioni was modelled to bi-directional three lumped mass vibration system. Dead weight 1.0 ton was cnsidered per 1.0 m x m horizontal area of a floor or of a roof. The slabs and beeams were assumed rigid. Flexural strength of each column section My was calculated according to the ACI method (Ref. 2), using 180 kg/(cm x cm) compressive strength of the concrete and 3000 kg/(cm x cm) yield strength of the reinforcements. The yield curvature of the section, ϕy was defined by yielding of any reinforcement. Secant yield flexural stiffness (EI)y=(Flexural strength My)/(yield curvature ϕy). By summing up My and (EI)y of all the columns in the story, Qy(yield story shear force) and δy(yield story displacement) were obtained. From zero to (Qy/2), the story was assumed to behave elastically. After δy, $\Delta Q/\Delta\delta$ was assumed to be $(1/100)\cdot[\Delta Q/\Delta\delta(elastic)]$. Thus, with respect to the directions EW and NS, two tri-linear skeleton Q-δ curves for each story were obtained. The analytical model of the house is illustrated in Fig. 10. Bi-directional [Q(EW),Q(NS)]-[δ(EW),δ(NS)] relation was formulated in Ref. 3 using the concept of plastic potential, and the intact formulation of Ref. 3 was applied to this analysis. According to the formulation in Ref. 3, the restoring force model becomes so called degrading-tri-linear-model, in case of uni-directional displacement history. Masonry wall of the concrete block in the 1st story was replaced with R/C wall of 3cm thickness in the analysis.

Damping coefficient matrix [C](6x6)=[C(EW)+C(NS)], [C(EW)](3x3)=$2\cdot\omega$(EW)$\cdot$h$\cdot$[M](3x3), [C(NS)](3x3)=$2\cdot\omega$(NS)$\cdot$h$\cdot$[M](3x3), ω: 1st initial natural circular frequency, (6x6) and (3x3) indicate the matrix size , and (EW) and (NS) indicate the directions, h: damping factor=0.01, [M]: mass matrix.

Bi-directional non-linear response analysis to the acceleration, STURNO EW, NS was carried out from the outset to 20 seconds. As the results of the analysis, [time]-[2nd story displacement components δ(EW) in the EW direction] and [time]-[δ(NS)] curves are shown in Fig. 11. The orbit of 2nd story displacement in δ(EW)-δ(NS) planes is shown in Fig. 12. [2nd story shear force Q]-[2nd story displacement δ] relation projected on Q(EW)-δ(EW) and Q(NS)-δ(NS) planes is shown in Fig. 13. The maximum 2nd story displacement in the EW direction was about 30cm. The maximum story drift was about 1/10 rad. It could be considered that the analytical results explained well the state of the damage as shown in photos. 3 and 4.

The water tank structure in Conza della Campania was modelled to bi-directional one mass system. Initial elastic stiffness of the analytical model was obtained by space frame analysis in which flexure, shear, tortion and axial deformation of each member were considered. Flexural strength My and secant yeild flexural stiffness (EI)y were calculated, using 180kg/(cm x cm) compression strength of concrete and 3000kg/(cm x cm) yield strength of the reinforcements. Strength of the space frame Qy was obtained from flexural strengths of members by the method of virtual work. Secant yield stiffness of the space frame was calculated by replacing elastic flexural stiffness (EI)e of each member with (EI)y. From zero to (Qy/2), the structure was assumed to behave elastically, and after yielding displacement δy, $\Delta Q/\Delta\delta=(1/100)\cdot[\Delta Q/\Delta\delta(\text{elastic})]$. Thus two tri-linear skeleton Q-δ Curves of the space frame were obtained with respect to X and Y directions. In this case, two Q-δ curves were almost same and they were averaged in the vibration model as shown in Fig. 10. Damping matrix [C](2x2) of this model was made by the same procedure as that of apartment house. The value of damping factor was 0.01.

In this study, three cases of water volume in the tank, i.e. 0%, 50% and 100%, were considered. [Time]-[displacement δ] relation in case of 50% water volume is shown in Fig. 15. Displacement orbits in case of 0%, 50% and 100% water volume are shown in Figs. 16, 17 and 18. The results of the response analysis could be considered to explain well the state of damage to the structure.

CONCLUSION

Regarding two R/C structures damaged during the South Italy earthquake of 1980, field survey and response analysis were carried out. The one was a structure of three story apartment house in Lioni, and the other a water tank of about 18 meters height in Conza della Campania.

The analytical model was a bi-directional non-linear lumped mass system. The input accelerations were the NS and EW components recorded at Sturno. The observed damage states of both structures were well explained by the analytical results introduced in this paper.

ACKNOWLEDGEMENT

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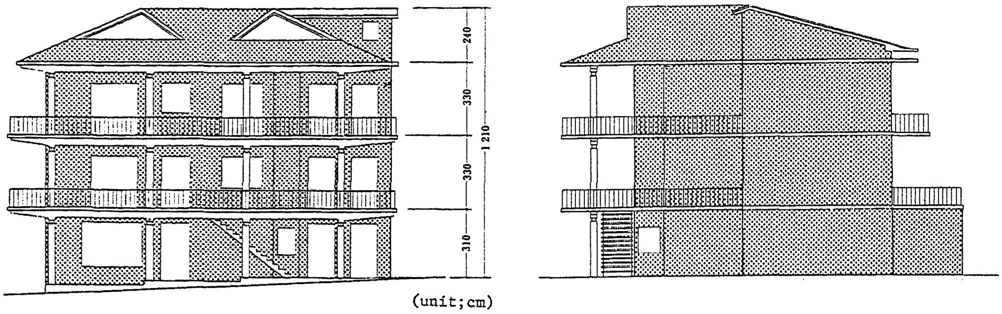

Fig.1 South and East Elevations of the R/C Apartment House

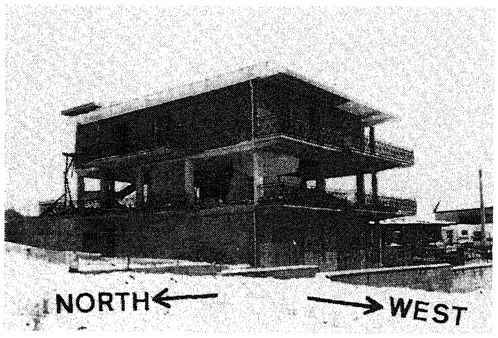

Photo.1 Whole View

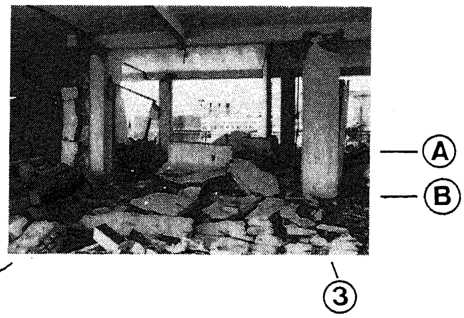

Photo.2 Situation of 2nd Story

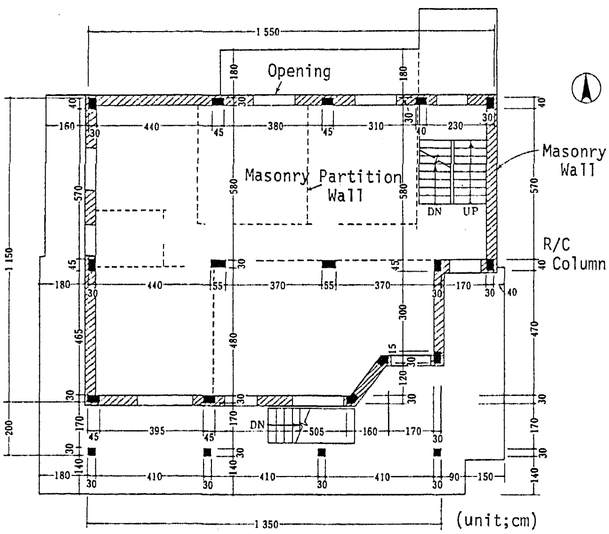

Fig.2 Horizontal Section of 2nd Story

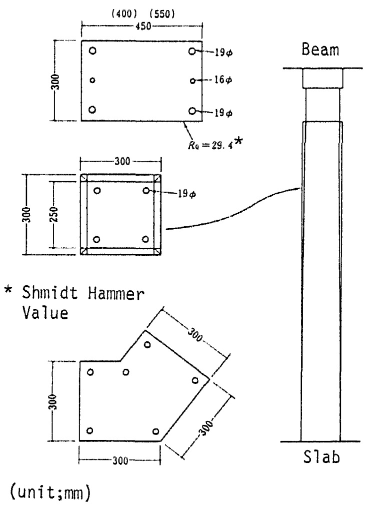

Fig.3 Detail of Columns

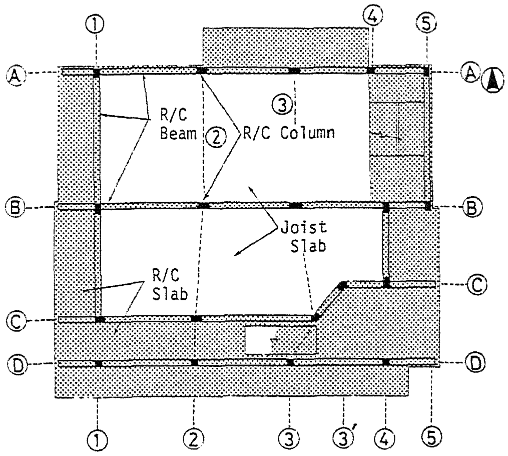

Fig.4 Slab and Beam System, and Notation of Column Lines

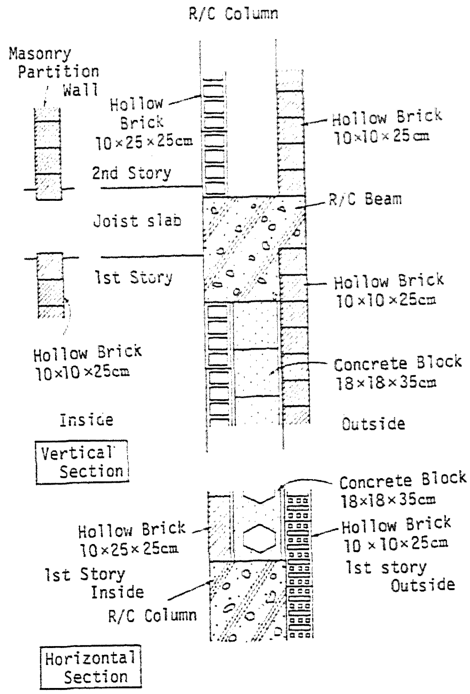

Fig.5 Detail of Walls

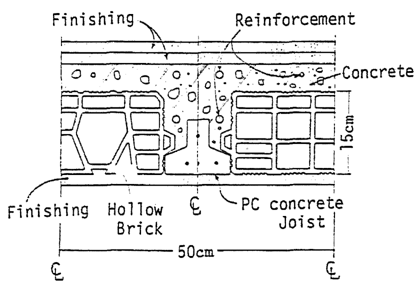

Fig.6 Typical Joist Slab Constitution

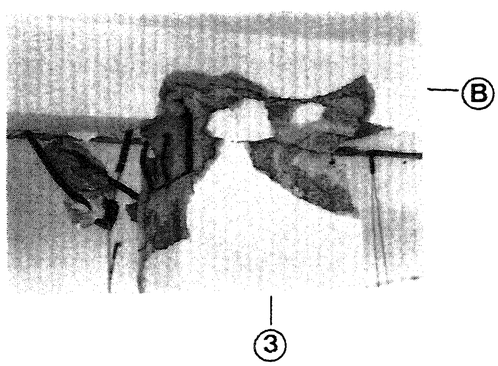

Photo.4 Damage to the 2nd Story Column TOP

Photo.3 Damage to the 2nd Story Column TOP

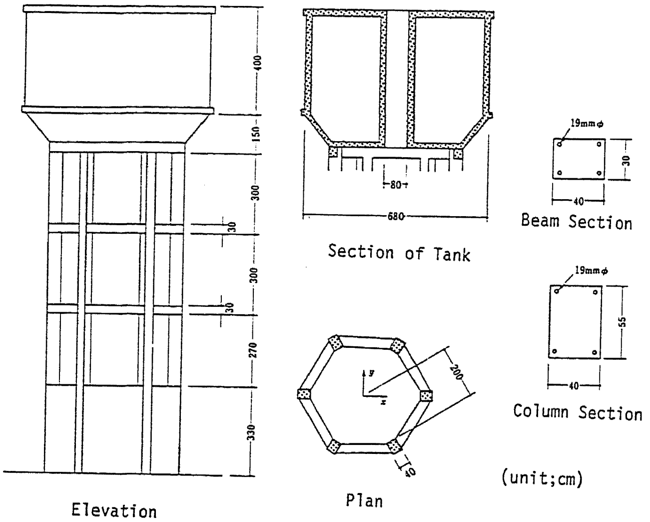

Fig.7 Outline of the Water Tank

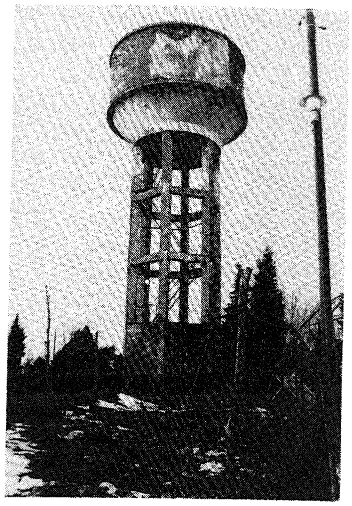

Photo.5 The Water Tank

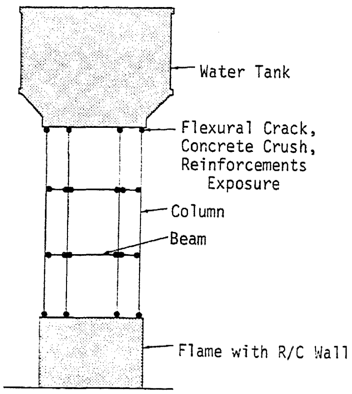

Fig.8 Outline of Damage

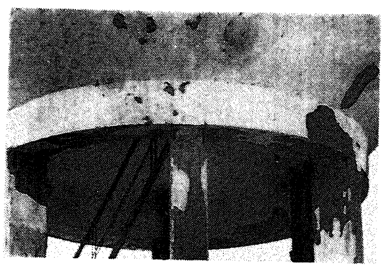

Photo.6 Damage to the Column Top

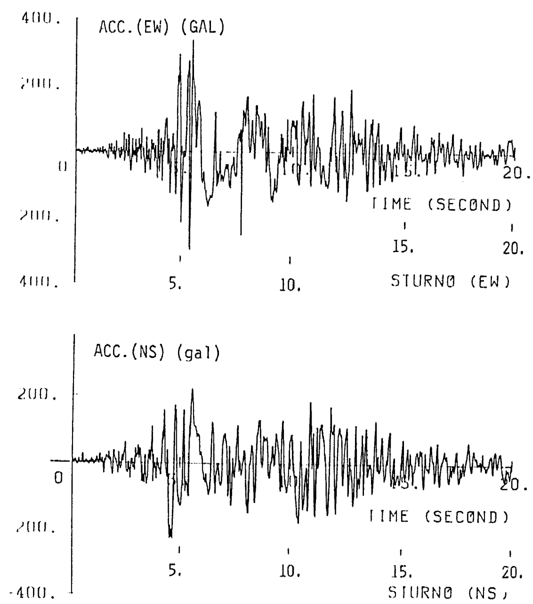

Fig.9 Accelerations,Sturno EW,NS

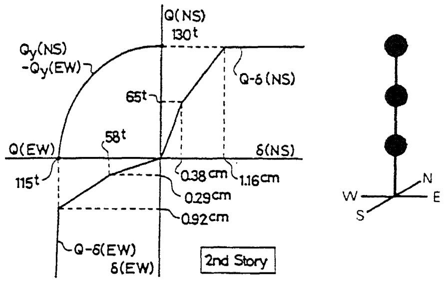

Fig.10 Model of Analysis

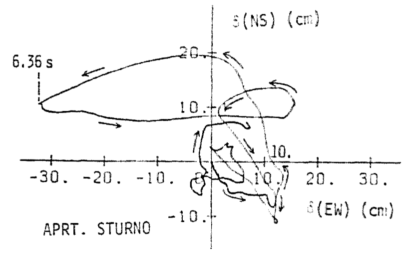

Fig.12 Orbit of 2nd story Displacement

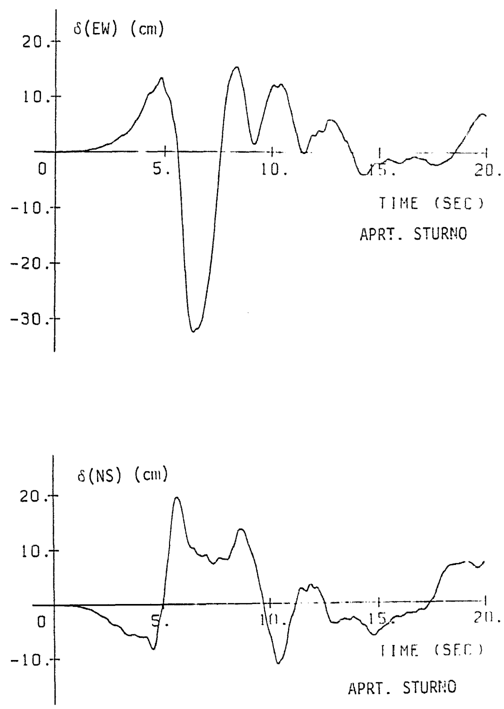

Fig.11 [Time]-[2nd Story Displacement, δ] Relation

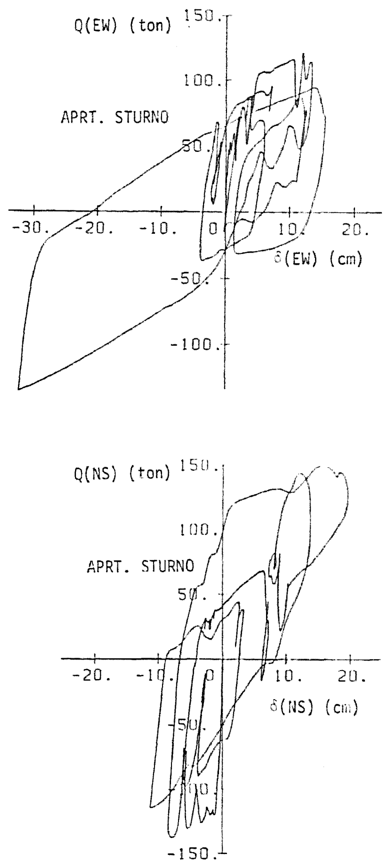

Fig.13 [2nd Story Shear Force,Q]-[2nd Story Displacement,δ] Relation

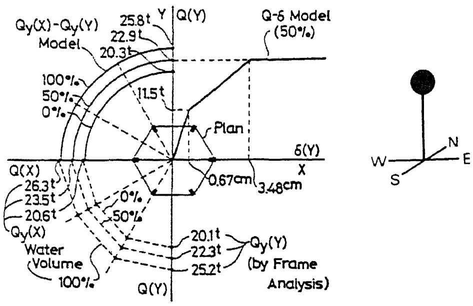

Fig.14 Model of Analysis

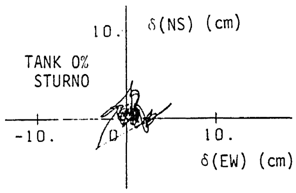

Fig.16
Displacement Orbit in Case of 0% Water Volume

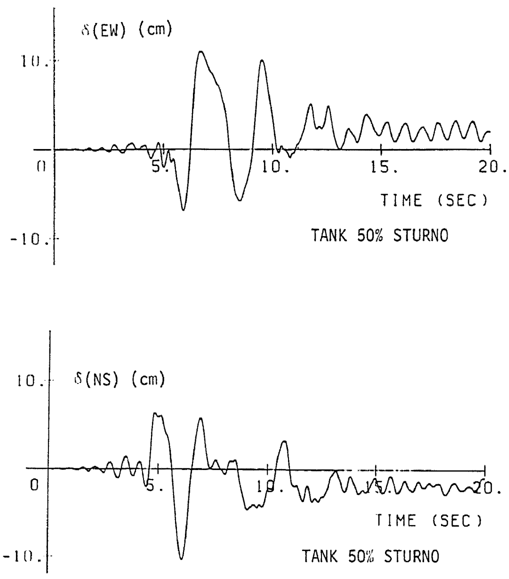

Fig.15 Time-Displacement, δ Relation in Case of 50% Water Volume

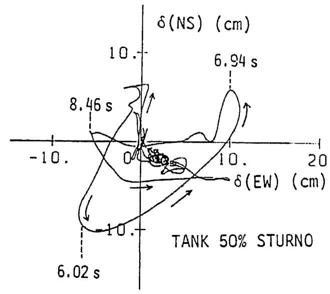

Fig.17
Displacement Orbit in case of 50% Water volume

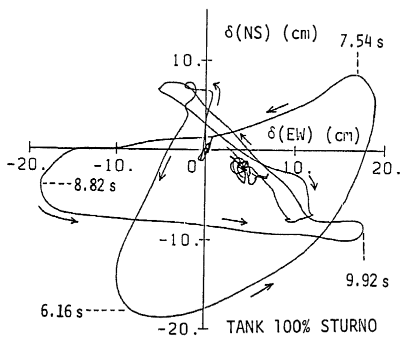

Fig.18
Displasement Orbit in case of 100% Water Volume