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EXPERIENCES ABOUT THE BEHAVIOR OF BUILDINGS DURING THE EARTHQUAKE OF OCTOBER 1995 IN PUERTO VALLARTA AND MANZANILLO, MEXICO.

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ABSTRACT

The effects of the 1995 Colima Earthquake are summaraized. Six reinforced concrete buildings that suffered different levels of damage are described in detail including one collapsed and other more that is under being demolish. For four of these buildings it was possible to obtain the structurals drawings; only for two of them a preliminary dynamic analysis has been performed. Recommendations on earthquake resistant design of reinforced concrete buildings are developed from this study.

Keywords: Damage, structural behavior, reinforced concrete buildings.

INTRODUCTION

On October 9, 1995 at 9:36 A.M. local time an earthquake of magnitude Ms=7.5 occured in front of the Colima Coast at a depth of 30 km., according to the Servicio Sismológico Nacional. The maximun ground acceleration was 0.4 g. at the Manzanillo Power Station (40 km from the epicenter).
The effects of the 1995 earthquake offshore the port of Manzanillo, was a test in the ability of building structures to withstand seismic induced forces, mainly in the Manzanillo Bay and Puerto Vallarta, Jal., both of them very important resorts

The highest level of damages occurred in Manzanillo where two buildings collapsed, 40 people were killed and more than 100 were injured. Most of the modern hotels and condominium buildings with reinforced concrete frames performed satisfactorily, with only non structural damages, e.g. cracking of masonry walls. Most of the one-story buildings performed well with limited cracking in walls. In the case of two-story buildings damage in walls was more extended. Two concrete continuous bridges with 30 m span, suffered damage to the abutments due to soil lateral spreating. More information about damages may be found in ref. 1, EERI (1995) and 2, EQE (1995).

Cihuatlan, a small town in Jalisco state, a large number of houses collapsed killing 10 people. Many others showed several damage. A four story hotel in Melaque partially collapsed, due to excesive mass of three large water tanks on the roof. In Barra de Navidad, located about 40 km north of Manzanillo, several one and two story structures partially or totaly collapsed.

To the north of Jalisco, in Puerto Vallarta, hotels are primarily reinforced concrete frame construction with infill masonry walls. Most of them performed quite well, like in Manzanillo, with only damage of masonry walls. Only three buildings suffered severe structural damage. More general information is in ref. 3. The maximum ground acceleration recorded was 0.12 g in N-S direction, (ref. 4)

In the case of Puerto Vallarta it is important to note that all buildings with structural and non structural damage are located in the preliminary named transition soil and most of the others placed on the preliminary firm or rock soil with almost non structural damage.

CASE HISTORIES

Several of mid-rise and high rise reinforced concrete buildings, in Puerto Vallarta and Manzanillo, wich are the most common practice, are described to show some experiences derived from their behaviour during the mentioned earthquake.
The date shown for each building indicates the year of structural design and construction.
The evaluation methodology used in all the buildings here presented, consists of a visual inspection of each building after the earthquake to identify the level of damage structural or non structural. When it was possible to obtain the structural drawings, they aid in having a more specific idea about the causes that provoked the damage, and if this corresponded reasonably well with their observed performance.
To improve our understanding only two buildings with structural damage were studied by means of dynamic analyses.

BPV 1 BUILDING

This is a 12 story building located in the preliminary so called transition zone, compacted sands.
The structure was cast in place (1983) with reinforced concrete beams and columns forming frames in both directions. Its plan is rectangular with 2 bays in the short (transverse) direction and 8 bays in the longitudinal direction. The elevator and staircase shafts are outside the rectangle (Fig. 1) The foundation is a concrete box with grade-beams.
All bays in the transverse direction between the columns axis, were infilled with brick walls and significantly contributied to the lateral stiffness.
In the longitudinal direction, are also infilled with walls but with a window just below the beam (this occurs only on axis 3 near the corridor). In the interior exists some infill walls in the same direction.

A visual inspection of the building after the earthquake revealed extensive cracking in the masonry walls in the first five levels only in the longitudinal direction and at the connection between the elevator-staircase box and the building.
Most important damage occurred at the first level in four consecutives columns with severe cracking that formed shear plastic hinges (Fig. 1).
Only in the second level, important cracking appear at one of the four columns mentioned but significantly less than the others and with no formation of plastic hinge. No damage or cracking were found in the rest of the main structural members.
The principal cause that provoked the structural damage of the four columns in the lower level was the enormous rigidity of the longitudinal frame No. 3 stemming from the additional beam and the performing as "short columns" due to the infills walls.
It is very reasonable to conclude that if the additional beam were not positioned there and a good separation between the columns and the longitudinal infill walls to avoid their total length, the building really could have had a much better structural behaviour.
It is notorious that the stair box did not suffer structural cracking because it was only connected at one point with the main principal body.

The building was closed by the civil authorithies and now is being strengthened.

BPV 2 BUILDING

This is a 9 story building designed and constructed in 1973. Its plan is relatively small and eloganted with 3 bays in the short direction and 7 bays in the longitudinal direction (Fig. 2).
The structure is cast in place with reinforced concrete columns and a flat waffle slab. Most of the infill walls are on sheet-rock. The arches on the facades were supported by columns.
The foundation is a concrete box with grade beams on a compacted sand soil.

An inspection to the building after the earthquake revealed in the facades full cracking of "false" columns of masonry walls only, because the archs were supporting on the true and false columns. of (See photo in Fig.2) forming a frame with a railing of about 1 m depth. All this happened in the 4 firsts levels.
Two of the north facade columns cracked because the presence of the railing mentioned, which makes the columns work , as "short columns".
Some construction defects were detected at the slab-column connections of the staircase framing because of bad anchoraged ending bars and the absence of stirrups at the joint.
In several cases corrosion of steel reinforcement was evident.
A bad anchorage of the stairs, that caused severe cracking in the concrete near the collapse in two cases.
No other damage was detected in the rest of the main structural members.

Because of the orientation of columns and span size in the short direction, it is evident that it is a structure with much more rigidity in the transverse direction than in the longitudinal direction. This has been confirmed, through dynamic analyses were the period of first mode was 1.3s in the short direction and 1.9s in the other, and consequently the computed lateral displacements were extremely larger in the longitudinal direction. This building in now under rehabilitation.

BPV 3 BUILDING

These are six separated buildings of 13 stories with four bays in the longitudinal direction and only one bay in the transverse direction. In the two first levels, the building has in the short direction one more bay on each side. The structure was cast in place with reinforced concrete columns and beams (1973).
The tower is founded beneath a basement on a foundation box. The rest of the columns of two levels are supported by footings.

After the earthquake, the visual inspection showed diagonal cracking in the masonry walls and falling of some ceiling panels.
One of the six buildings showed some little tilting in the short direction. Tilting was 0.4% of the building heigth.
Another non structural damage occured in the longitudinal direction because the building was pounding with adjacent structures and provoked falling of tiles. This happend also because of the orientation of columns in the short direction.
Lateral displacements were important causing the cracking of some masonry walls in the transverse direction and pounding between the structures in the longitudinal direction showing that the building separation was not enough. This building will be upgraded

BPV 4 BUILDING

This twelve-story building was located at the Marine Zone on compacted sands.

It is constituted by three separate buildings arranged in a "U" form (Fig. 3).
Structures 1 and 2 (begining 1985) have cast in place reinforced concrete waffle slabs supported on steel columns.
Structure No.3 has a combination of cast in place reinforced concrete beams with flat waffle slabs supported on concrete columns. (end of 1985)
Masonry walls were placed in two perpendicular directions.
The foundation of the three buildings are continuos footings with grade beams.

A visual inspection of these buildings, principally number 1, revealed wide and extensive cracking in most of the masonry walls in both directions.
In some cases, large pieces of 1 m^2 fell to the floor. In others, cracks of 10 cm. wide or pieces of walls were dislodged 15 cm. outside its original plane. (see photo Fig. 3).
On the floor it was possible to see several cracks on the top of the flat waffle slab.
Damage on steel column was detected in the second level near the connection to the slab due to local buckling. All this happened in the first five 3 stories.
Regarding structure 3 the level and number of cracks in masonry walls was significantly lower than in 1 and 2, but not to be neglected. The construction joint, between structures 2 and 3, small walls of this the railings of this latter building collapsed in almost levels because of the pounding between them.

The enormous lateral flexibility and low torsional stiffness of this kind of structure made by flat waffle slabs and light steel columns, caused a very important interstory drift, which in turn provoked the large cracking in masonry walls. Poor quality material in walls, also contributed to the damage.
Nevertheless,it is very important to mention that given the level of destruction of these walls, the building should have experienced a greater nonlinear behaviour than the one perceived from its level of damage, that could provoke the partial or total collapse of the structure.
Now, the structure is on the way of total demolition.

BM 5 BUILDING

This was an eight story building located on the bay of Manzanillo. Its construction dates back to 1980.
The structure was a rectangle with an eccentrical staircase in reinforced concrete cast in place structure with slabs and beams on the first level (transfer girders) supported by concrete columns, with few masonry walls. Other columns started at this first level until the last one and supported a flat waffle slab with interior infill masonry walls. (Fig. 4). The height of the first level was greater than the rest. The foundation were footings with grade beams on compacted sands.
After the 1985 earthquakes, the building sufferd several structural damages and was closed for two years.
This structure was finally reinforced, jacketing with concrete and additional steel the section of some columns at the ground story and additional external stirrups in "U" form, in main girders of this story.

The structure complety collapsed during the 1995 earthquake, resulting in at least 30 deaths.
During the visual inspection it was possible to observe a high level of damage in the columns due to the collapse mechanism, forming flexural plastic hinges and almost no damage on the flat slabs.

Longitudinal steel reinforcement in columns, was formed with two bars at each corner and the separation of stirrups (about 25 cm.) showed that was largely insufficient to support the high demands of ductility hence contributed to the formation of plastic hinges at the ends.
The conclutions of this collapse could be enumerated as follows:
First, the large discontinuity between the first and the rest of levels, with columns starting at the middle span of the beams in the longitudinal direction.

And second, consequently the enormous ductility demand for the columns at the ground level and the magnified effects due to the big difference between the presence of masonry walls in the upper levels yielded the structure working with a weak first story.

BM 6 BUILDING

This is a nine story building placed on compacted sands. Its plan is formend by two structures with only one commun axis, near the concrete box of the staircase. (Fig. 5).
The structure is a reinforced concrete waffle slab supported on columns of the same material. The foundation are isolated footings (1973).

A visual inspection of the building after the earthquake, revealed extensive diagonal cracking in the masonry walls in both structures principally in the first five levels. No cracks were found in the main structural members.
Because of the insufficient of the reinforced concrete waffle slabs used (total depth 25 cm.) and the sections and steel of the reinforced concrete columns, it is obvius that lateral displacements were extremely large with a very important interstory drift, but limited because of the masonry walls and for that reason the cracking was very significant.
Another remark is the fact that only one frame connects both structures near the concrete box, with a high probability to crack in the slab, forming a natural separation between this almost different structures. This is a typical case without a good horizontal diaphragm. The building is now closed and will be upgraded.

CONCLUSIONS AND RECOMMENDATIONS

Most of the of mid-rise and high rise reinforced concrete building structures framing with beams and columns performed well with damage concentrated in masonry walls, especially in the longitudinal direction because of the orientation of columns. The treatment of these masonry walls requires special detailing .
The great lateral flexibility of the flat waffle slab provoked much more damages in buildings.
Nevertheless, is important to mention that in general, those buildings were designed between the 70's and 80's, with low requierements for seismic design. Current codes require, the structural system be laterally stiffer and stronger than that provided slender frame members used in the past. This can be attained by using more robust columns and beams, but preferably, by adding stiffening members such as shear walls or braces.
Special attention requires the rehabilitation of structural damaged buildings to avoid cases like the mentionned collapsed structure.
Soil and site conditions have greatly influenced the shaking level suffered by buildings, especially those placed on compacted sands.
The frequent seismic activity in Colima and Jalisco Coasts and the important number of buildings, makes it particulary convenient site for seismic instrumentation of buildings.
It must be present that the largest earthquake occurred this century in Mexico, was the Jalisco earthquake on june 3th, 1932 of Ms= 8.2, in the subduction zone of the Rivera Plate.

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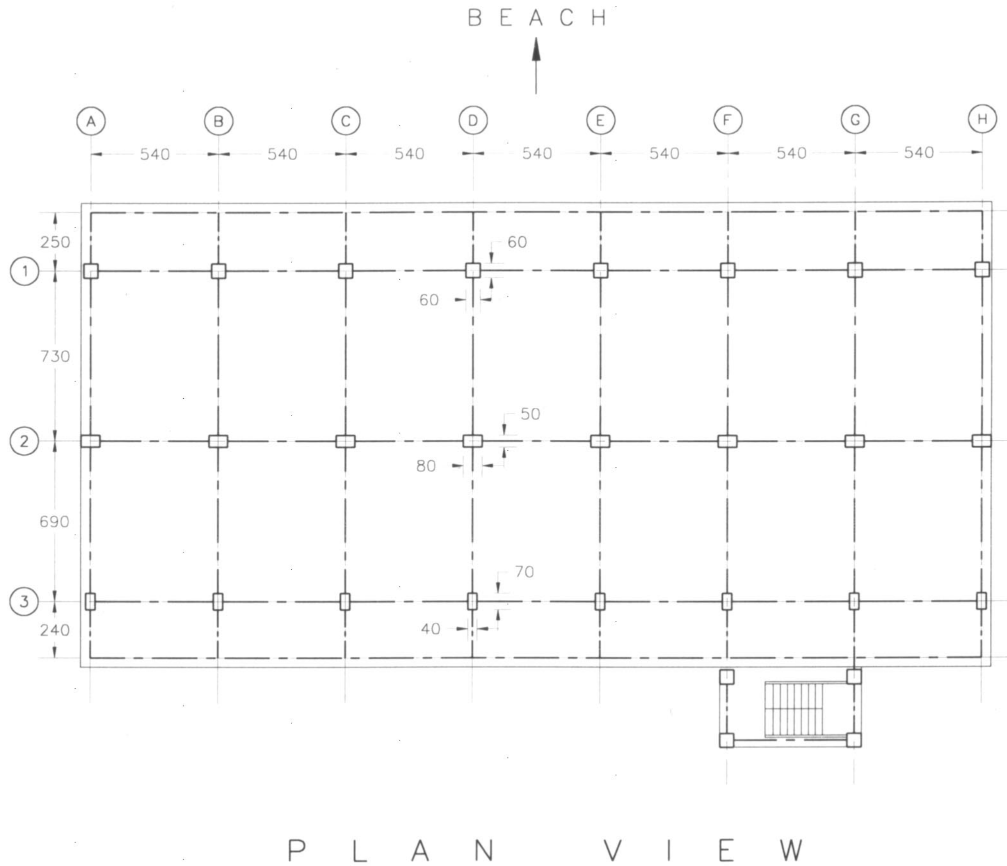

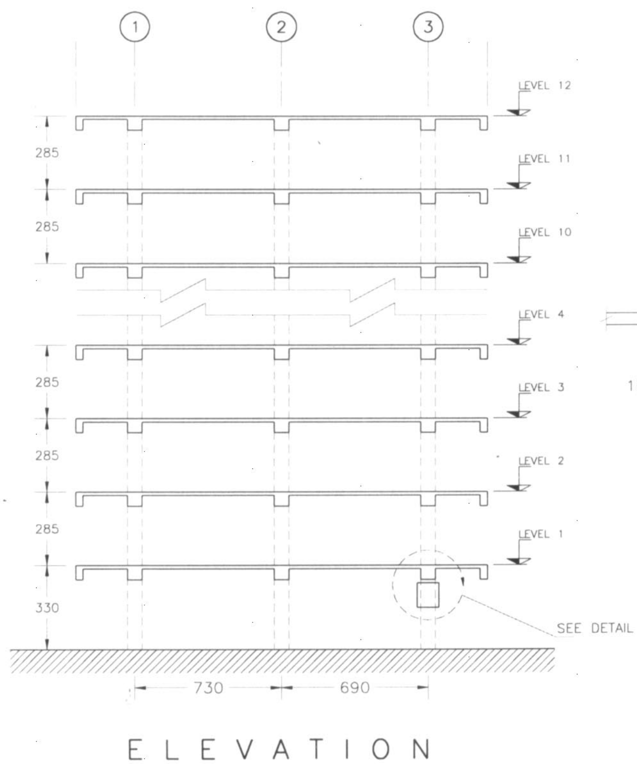

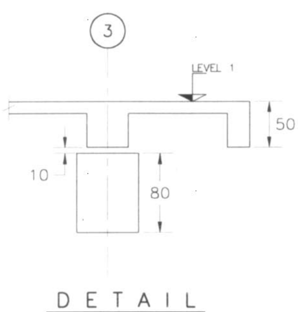

Fig. 1 BPV1 Building

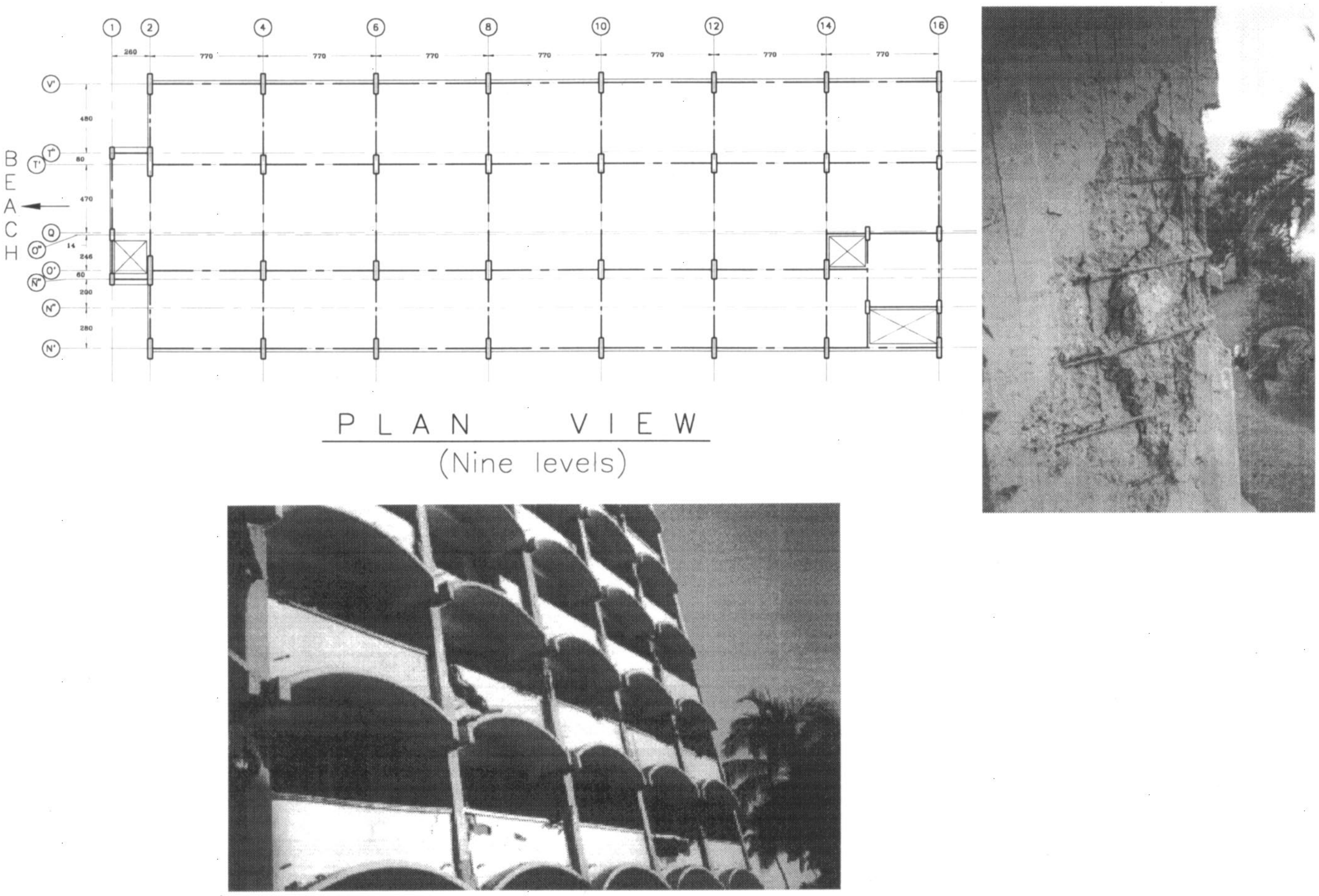

Fig. 2 BPV2 Building

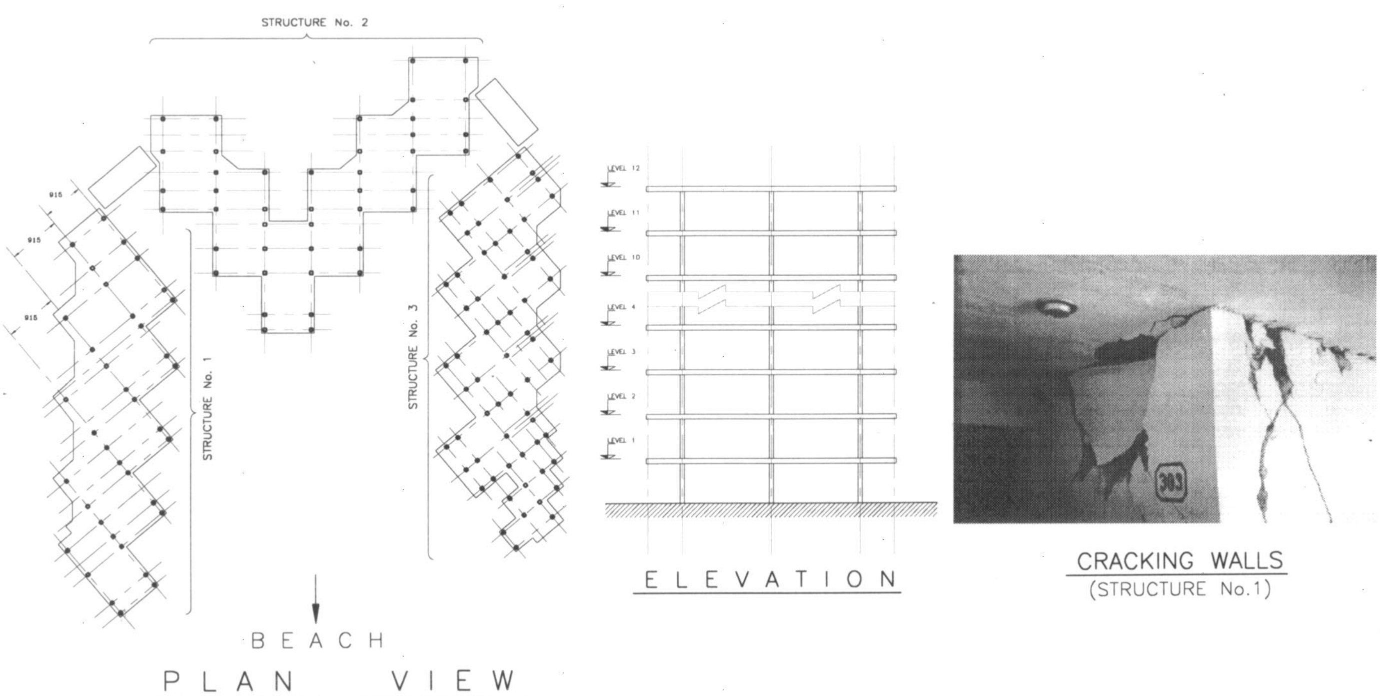

Fig. 3 BPV4 Building

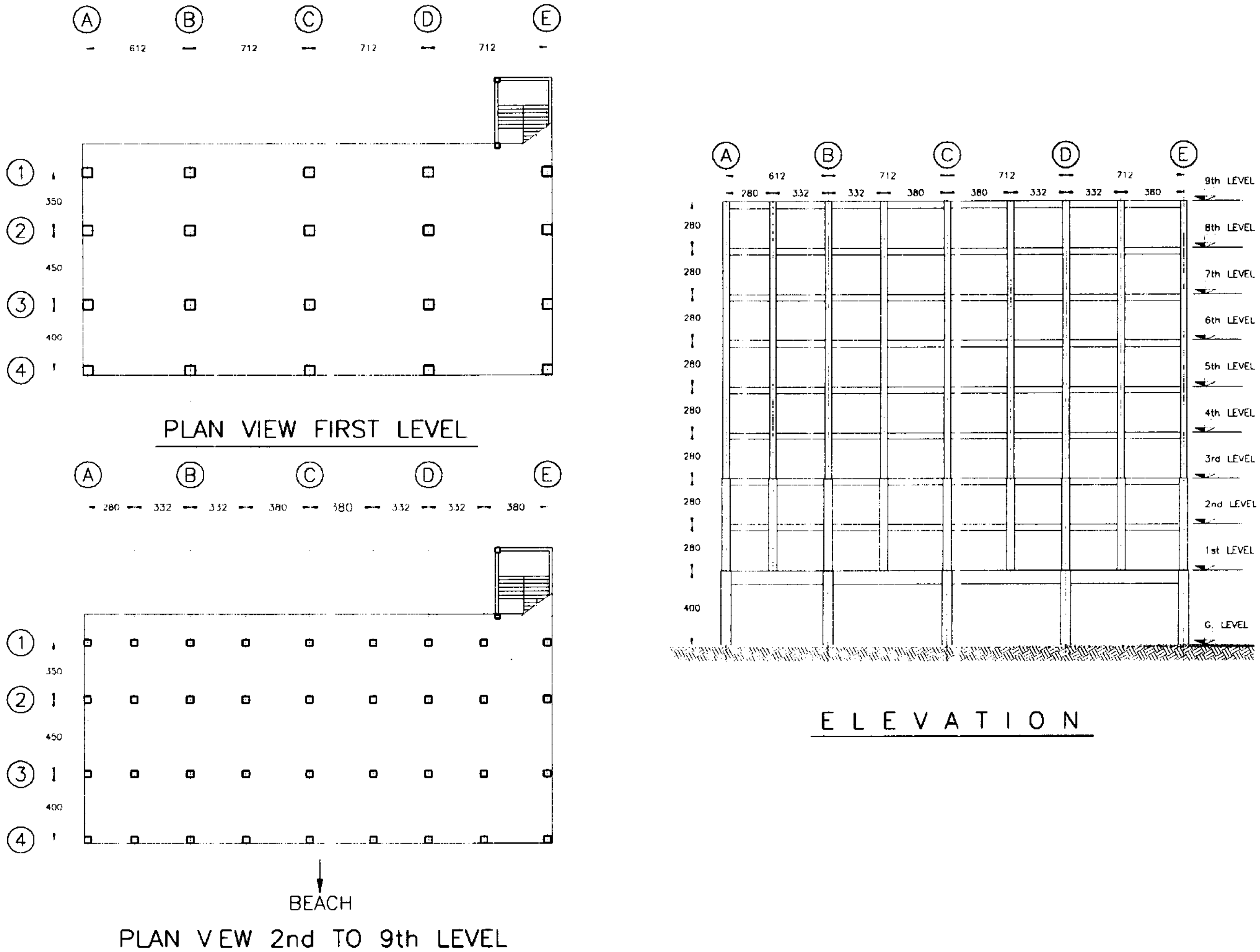

Fig. 4 BM5 Building

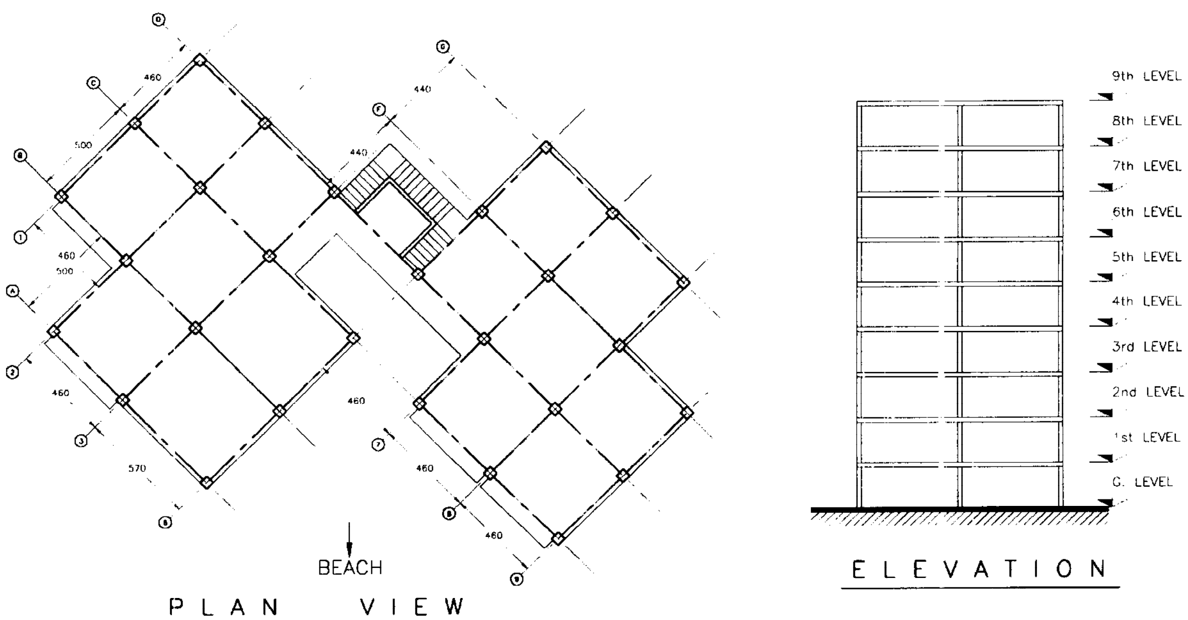

Fig. 5 BM6 Building