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DESIGN OF A VERY IRREGULAR TOURISTIC COMPLEX IN A REGION OF HIGH SEISMICITY

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ABSTRACT

The seismic design of a very irregular building complex is presented. Architectural constraints imposed serious structural design challenges in this project. First, the project had to incorporate an existing building designed with and older building code, therefore, inadequate when compared to the current seismic requirements for the area. Different retrofit strategies were studied, but linking the existing structure to the two new adjacent towers resulted in the most economical solution. The adjacent towers were designed to carry the excess lateral loads in the existing building to avoid major retrofit. Furthermore, architectural considerations demanded different floor elevations in parts of the same story, leading to complicated connection details. Another important difficulty was encountered when designing the foundation of the tall slender towers on organic soil (peat).

The design challenges became even more critical due to the high seismicity of the area. A site spectra was developed to obtain a better estimate of the input motion likely to occur. This paper summarizes relevant analysis and design considerations, necessary to ensure an adequate response performance of the very irregular and difficult building complex.

KEYWORDS

Design; Retrofit; Irregular Structures; Site Spectra; Connections.

INTRODUCTION

As part of the diverse Mexican geographical landscape, 3500 Km of littorals are noteworthy, among them, the area known as "*Costa Dorada*" along the pacific ocean, from Mazatlán Sinaloa to Huatulco Oaxaca, have prominent vacational facilities. One of the most important ones is Ixtapa, in the state of Guerrero, located about 200 Km west from Acapulco, and about 20 Km form Zihuatanejo, in an area classified as having a high seismic risk. Located in this tourist center, the vacational complex Aramar is to be built. Construction started towards the end of 1984, and during the 1985 seismic events, one of the buildings was under construction, with 9 stories completed out of 15 in the original project.

ARCHITECTURAL DESIGN

After the 1985 earthquake in Mexico, and the modifications to the building code requirements, the original project was modified. The new tourist complex consists of three buildings labeled A, B1-B-B2, and C-D. The towers are arranged in a semicircle with the center coinciding with the main swimming pool. The number of stories is variable, ranging from 5 in building A, to 15 in building C-D. Story heights are 5.20 m for the first floor, and 3.15 m for the typical floors. Figures 1 and 2 show a plan view and an elevation of the building complex.

Building A, located next to the beach, with dimensions 39.70 by 13.80 m, exhibits in plan an irregular geometry. In elevation the building varies in height, from 5 to 8 stories. Building B1-B-B2 consisted of three towers in the architectural project, that were linked to form a single tower, in order to enhance their seismic response. Tower B1, 16.10 by 13.80 in plan, is 10 stories high. Building B, the existing 9 story structure, with dimensions in plan of 28.80 by 14.00 m, is to be built to a total of 10 stories. Tower B2, 24.90 by 14.00 m in plan, varies from 10 stories at the end connected to tower B, to a total of 13 stories at the other end. Similarly, the architectural project had two more slender towers, C and D, that were interconnected to enhance their seismic response. Towers C and D are 17.60 by 14.00 m, and 13.80 by 29.40 m in plan, respectively. Towers C and D are both 15 stories.

The building complex include two towers with elevators and stairs. One of this towers was structurally connected to building B1-B-B2, while the other was linked to building C-D. Exterior walkways, 0.45 m below the floor level, communicate all the structures.

GEOTECHNICAL ASPECTS

From a geotechnical standpoint, according to the classification established in the building code for Guerrero, the building complex is located in soil type III. For design, mixed exploration techniques were used, including standard penetration tests, and exploration with undisturbed and disturbed soil samples. Using that information, the soil profile at the site was determined, and can be summarized according to:

a) From the ground level to about an average of 3.0 m depth, fill material consisting of silt and sandy silt with some gravels is found. Water content is 20%.

b) From 3.0 to about 8.6 meters depth, peat mixed with clay is found. The average water content is 300%, indicative of an organic soil.

c) In the area where building C-D is to be located, from 8.6 m to the maximum exploration depth, 30.0 m, highly compacted sandy silt with some shells and gravels was found. The average water content is 18%. For the area where buildings A and B1-B-B2 are to be built, the same material was found with intermediate layers, with variable thickness, of silty sandy clay.

Based on the soil conditions at the site, specially due to the presence of the layer of peat, the geometry of the project, and the magnitude of the loads transmitted to the foundation, the use of drilled piers was recommended. Circular piers were analyzed and designed, ranging from 1.2 m to 1.8 m in diameter, some of which include an angled bell. The existing building ,B , is supported by pile groups to the firm soil stratum.

STRUCTURAL DESCRIPTION

As described earlier, the building complex consists of three buildings (A, B1-B-B2, and C-D), that include two slender towers for the elevator and stairs. The architectural project imposed important challenges to the structural design due to the irregularities in plan and elevation. Another challenge for the structural

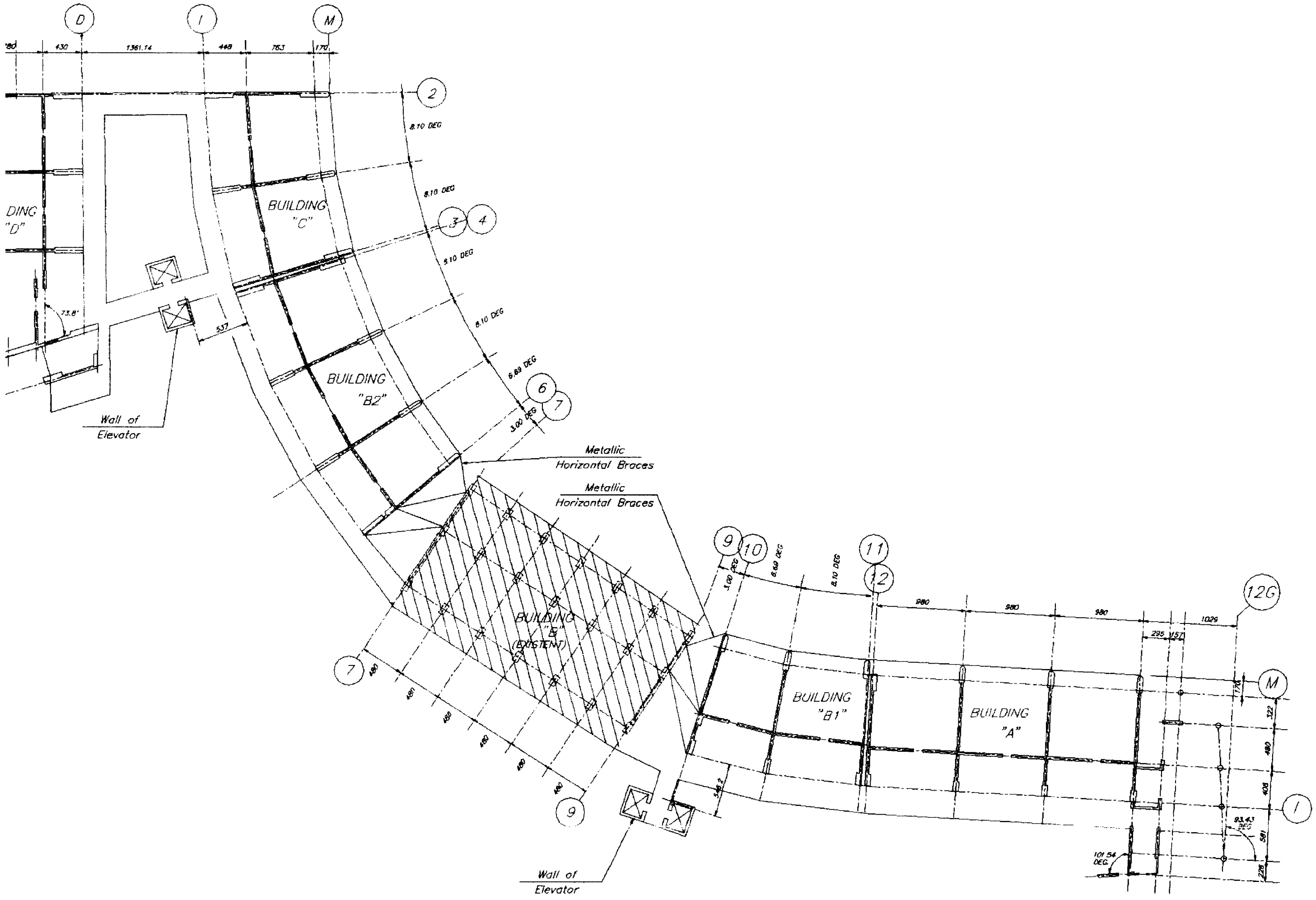

Fig. 1 Plan view of Aramar complex

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ARAMAR IXTAPA

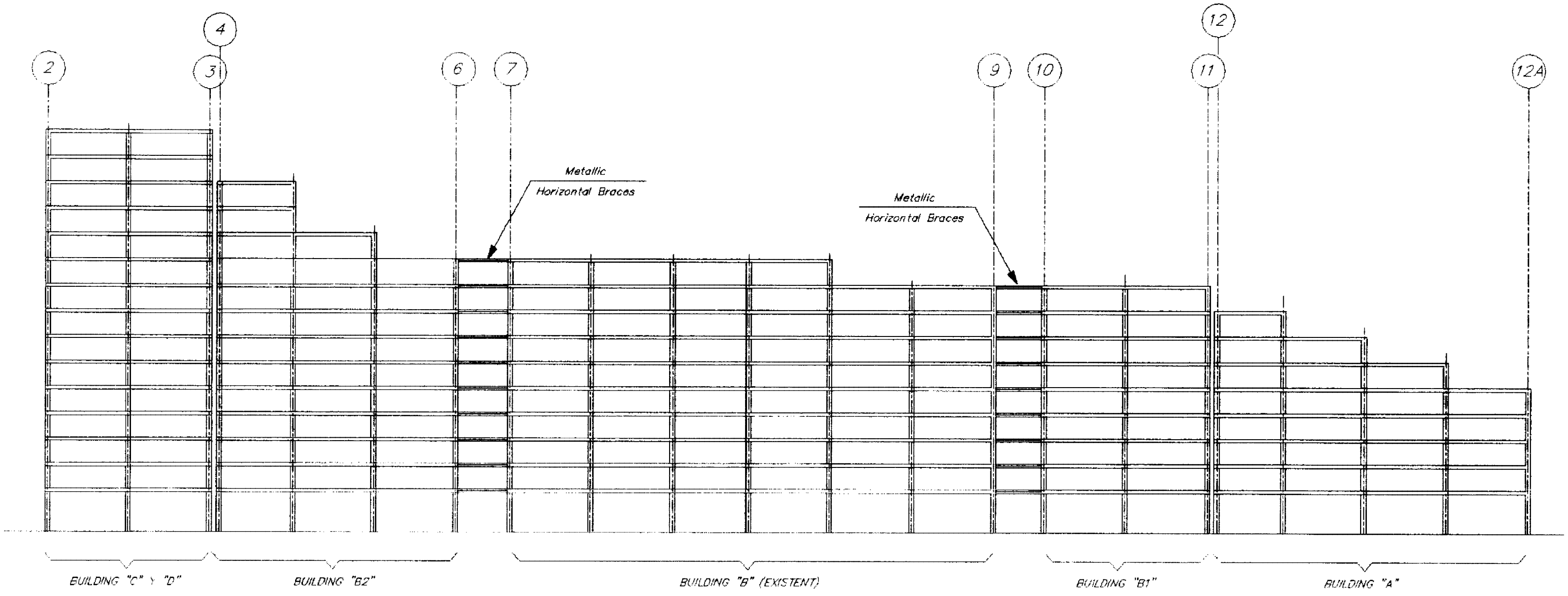

Fig. 2 Elevation

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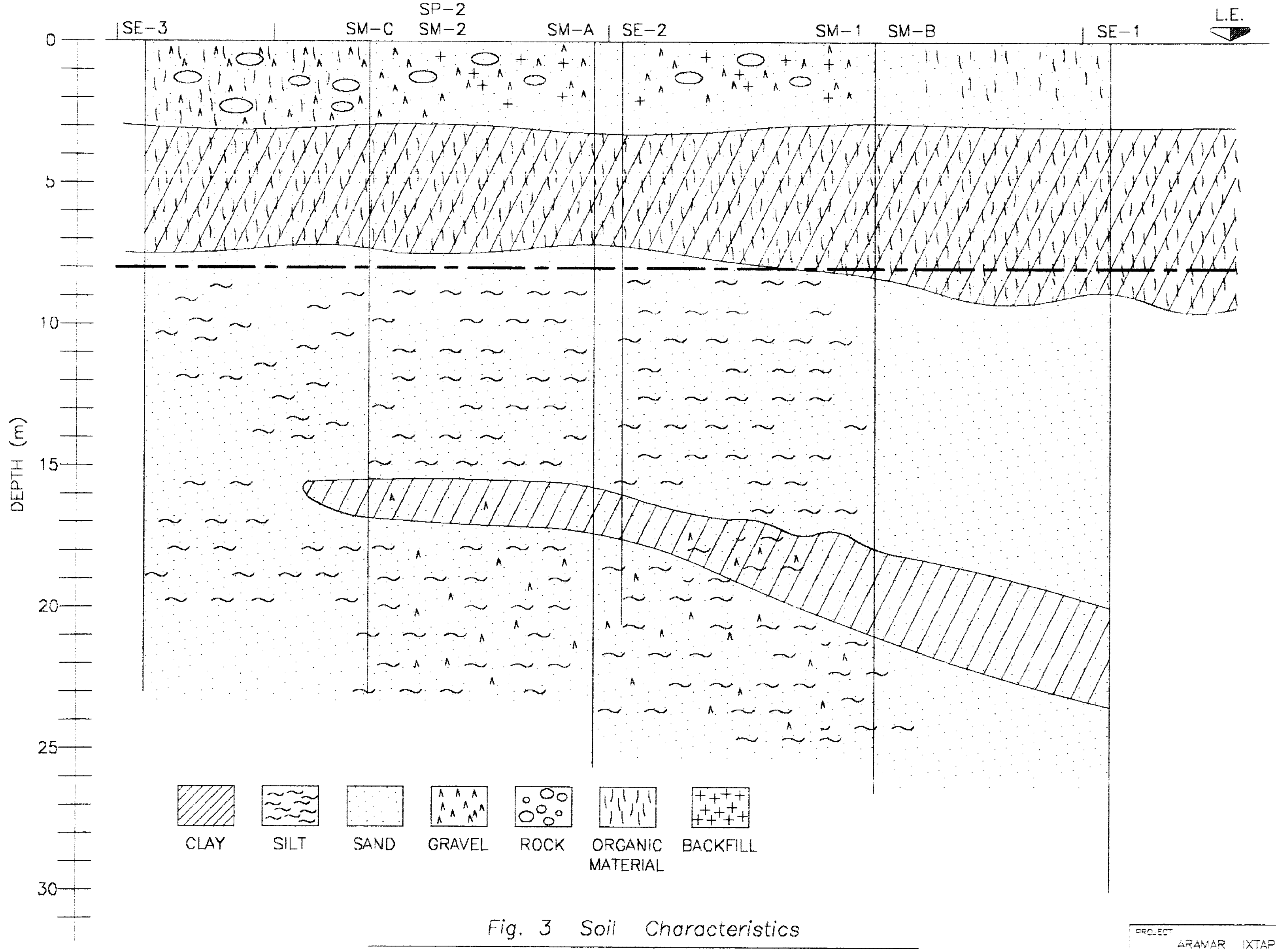

Fig. 3 Soil Characteristics

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design team was to integrate the existing building B, consisting of reinforced concrete moment resisting frames in both directions, but designed using the previous building code requirements of the area, and had to be retrofitted to comply with the new earthquake requirements.

A number of retrofit alternatives were studied to strengthen the existing building, but linking the structure to the adjacent new towers B1 and B2, resulted in the most economical solution. The towers were connected using metallic horizontal braces with a tubular section 32.4 cm in diameter. The new towers were designed to resist the excess lateral loads that could not be resisted by the existing building, and to reduce the lateral deflections of the system. Furthermore, two concrete shear walls were added at the ends of the existing building in order to reduce the maximum response of the system in the transverse direction. The new towers B1 and B2 have concrete shear walls in the transverse direction, with a thickness varying from 20 cm at the upper floors, to 40 cm at the foundation, and with a 60 cm width near the column connections. In the longitudinal direction, architectural constraints permitted concrete shear walls only at the interior column line, and moment resisting frames for the exterior ones. The floor consists of a post-tensioned 20 cm slab. Building A, the shortest building, located at the west end of the complex, was designed using a waffle slab system 40 cm in depth, with some of the main beams post-tensioned.

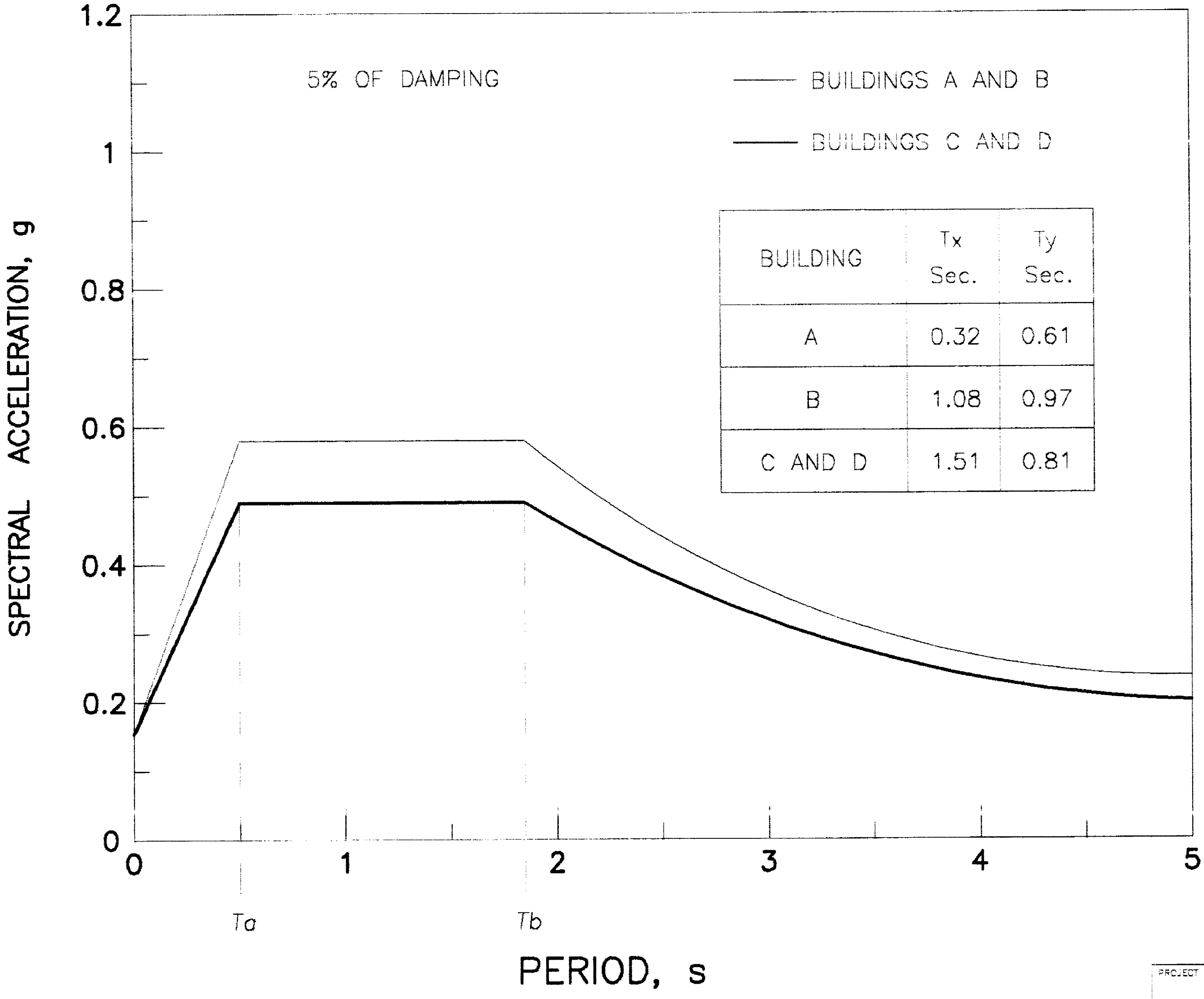
All of the buildings in the complex are linked at the foundation level by a grid of foundation beams supported on cast in place caissons, varying in depth from 10.25 m to 23.5 m. Since the caissons need to be drilled through highly compressible soils, including peat, these are to be built using a metallic form, the excavation is to be stabilized using slurry, and concrete is to be placed using the tremie method. Furthermore, some of the piers will require a bell ended bearing, in order to enhance bearing capacity of the foundation.

SEISMIC ANALYSIS AND DESIGN

The seismic analysis was performed using a three dimensional elastic model of the different towers that conform the complex. Three buildings models were made: tower A, towers B1-B-B2, and C-D. For each of the three building structures, a modal analysis was performed to obtain the lateral earthquake forces acting in the structure.

The building complex is located in the earthquake risk Zone D, that is region of higher seismic risk in Mexico. According to the current seismic design requirements, a building located in that area on highly compressible soil, has a seismic coefficient of 0.86, in the range of characteristic periods from $T_a = 0$ sec to $T_b = 1.4$ sec, with a value of $r = 2/3$ for the descending portion of the spectrum. According to the code specifications, the elastic demand forces could be reduced by a factor Q, that takes into account the energy dissipation capacity of the structural system proposed. A value of $Q = 3$ was used for the buildings. That reduction factor had to be reduced by a 20% due to the irregular geometry of the system.

During the 1985 seismic event, nearby stations recorded the event. Considering the local soil conditions, the type of foundation suggested for the project, the acceleration records of the 1985 event, a pair of site spectra were developed for the site (Romo, 1995). The site spectra indicate lower maximum response values than the Guerrero building code, therefore, allowing for some savings in the design, observing the allowable maximum seismic risk of the structure. Figure 3 presents the recommended site spectra. The maximum period for the plateau in the spectra were determined by multiplying by 1.2 the predominant inelastic period at the site (1.41 sec), that yields a value of 1.7 sec. The safety factor is to account for the uncertainties in the determination of the fundamental period of the structures, nonlinear effects, and possible failure mechanisms in the structures. The beginning period of the plateau in the spectra ($T_a = 0.5$ sec), was determined by multiplying the fundamental inelastic period at the site by 0.35, according to the recommendations for soft soils in the Mexico City building code. The exponent



BUILDING	Tx Sec.	Ty Sec.
A	0.32	0.61
B	1.08	0.97
C AND D	1.51	0.81

Fig. 4 Site spectrum

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controlling the rate of decay for longer periods was adjusted using the soil type III specifications in the Guerrero building code.

The site spectra developed are, for buildings A and B1-B-B2:

$$S_a = 0.15 + 0.86T \ ; \ \text{for } 0 < T \leq 0.5 \text{ sec}$$

$$S_a = 0.58 \ ; \ \text{for } 0.5 < T \leq 1.7 \text{ sec}$$

$$S_a = 0.58\left(\frac{1.7}{T}\right) \ ; \ \text{for } T > 1.7 \text{ sec}$$

for building C-D:

$$S_a = 0.15 + 0.68T \ ; \ \text{for } 0 < T \leq 0.5 \text{ sec}$$

$$S_a = 0.49 \ ; \ \text{for } 0.5 < T \leq 1.7 \text{ sec}$$

$$S_a = 0.49\left(\frac{1.7}{T}\right) \ ; \ \text{for } T > 1.7 \text{ sec}$$

where S_a is the maximum spectral acceleration in g's; and T is the period in seconds.

CONCLUSIONS

Due to the architectural constraints, the poor soil conditions, and the high seismic risk in the area, the ratio of reinforcing steel to square meters of construction was anticipated to be high. A value of 90 kg per square meter was obtained for the project, that is towards the highly reinforced end for this type of structures.

Another important aspect that must be emphasized, is the need for an understanding between engineers and architects, in order to create projects without unnecessary irregularities, that pose serious design problems, and often yield expensive solutions. In order to achieve a functional, safe, and economic design more interaction between all the areas involved in the project is necessary in the early, conceptual, stages of the design.

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