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SYNOPSIS This paper describes the design of a two-way ribbed mat used as the foundation of a tall aseismic building located in a very heavy seismic area of northern Venezuela. The soil description, the structural analysis and some construction provisions are also described. See mat in Fig. 8.

GENERAL

The structure described in this paper is used as foundation of a reinforced concrete aseismic Office building of 23 levels, 80 meters (263 ft) high, now under construction at Barquisimeto, Venezuela, which is a very heavy seismic area. That city is located near of the Boconó fault, one of the most active geologic faults of the country. See geologic map of northern Venezuela in the paper of Steinbrugge and Cluff (1968). The foundation was placed at a depth of 13 meters (43 ft) below the level of the perimetral streets of the site. See Figs. 1 and 2. The lateral and vertical load carrying systems of the building consists of R/C ductile moment resisting space frames, as defined by the Structural Engineers Association of California, SEAOC (1974).

SOIL DESCRIPTION

The subsoil profile, Fig. 2, is rather erratic showing a shallow topsoil of organic matter and fill, 2 meters (6.6 ft) thick, over a granular layer of pebbels and sandy gravel. From 6 meters (20 ft) on, appear different layers mainly silty sandy gravels with lenses of silty sandy clay, product of weathered transported shales. Between 16 and 22 meters (52-72 ft) there are sandstone and quartzitos with some silt and clay, overlying a silty grandly sand in a clay matrix. The borings found no groundwater level; there were adopted an allowable bearing capacity of 35 metric ton per square meter (50 psi) and a coefficient of subsoil reaction of about 15,000 metric ton per cubic meter (936 kips per cubic foot).

Fig. 1. Building's Site.

Fig. 2. Soil Profile.

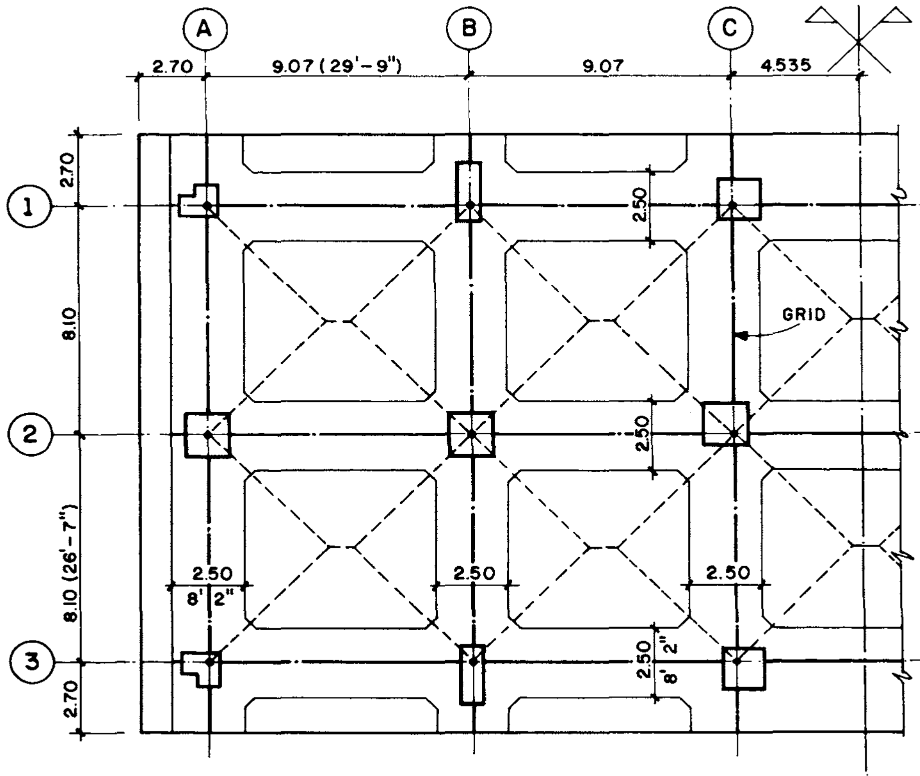

Fig. 3. Schematic Mat Plan

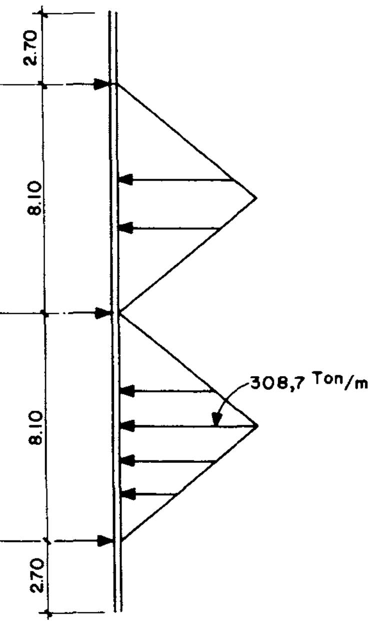

Fig. 4. Upward load at axe 'C'

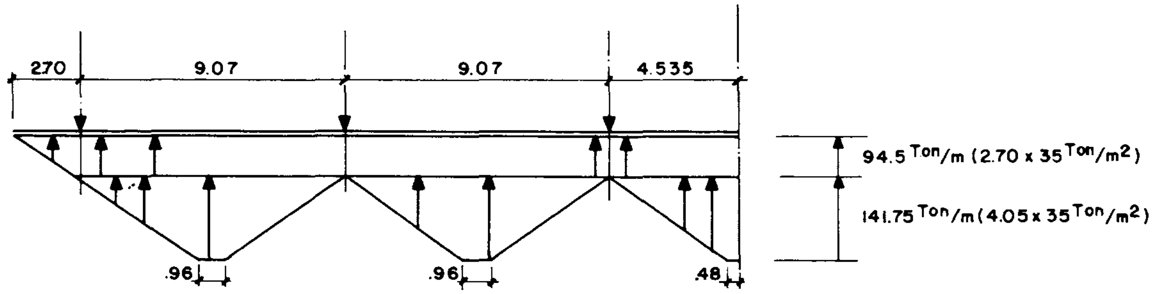

Fig. 5. Upward load at axes '1' and '3'

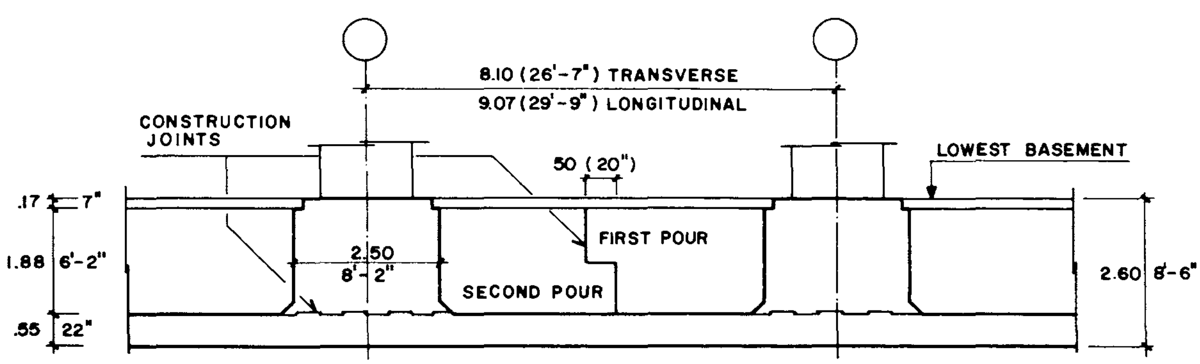

Fig. 6. Mat Schematic Section

It must be emphasized that all excavation walls remain improtected, vertical and stable during construction. The entire perimeter of the site was excavated 11 meters (36 ft) deep without any kind of temporary protection.

DESCRIPTION OF THE RIBBED MAT FOUNDATION

The mat is a rectangular reinforced concrete two way ribbed system constituted by stiff beams and a complete bottom solid slab, .55 meters (22 in.) thick. The overall dimensions of the mat, are: 50.75 x 21.60 meters (166 ft-6in. x 70 ft-10in.) having its ribs inverted in order to place the bottom slab directly against the ground on a horizontally leveled excavation bottom. The ribs are stiff beams 2.50 meters (8ft-2in.) wide x 2.60 meters (8ft-6in.) deep orthogonally placed forming a grid whose intersections points (nodes) intercept with the column axes producing rectangular panels of 8.10 x 9.07 meters (26 ft-7in. x 29 ft-9in.). The bottom slab is structurally supported by the inverted ribs forming two-way solid slab panels between the ribs. See Figs. 3 and 6. In order to use the lowest basement level, another R/C slab was placed on the tops of the inverted ribs. Some of the spaces between the ribs and the bottom slab were used as water storage tanks for the building needs.

MAT ANALYSIS AND DESIGN

Conditions of Rigidity or Flexibility

The analysis of the mat foundation was carried out assuming a linear distribution of the soil pressure. According to the procedure suggested by ACI Committee 436 (1966), the value of 'λ', as defined by formula number 6 of that procedure, resulted in

λ = .2091 for the transverse direction, and
λ = .2146 for the longitudinal direction of

the mat. The coefficient of subgrade reaction used in the formula number 6, was 15,000 metric ton per cubic meter (936 kips per cubic foot) as it was recommended in the subsoil investigation report. The values to determine the mat's rigidity or flexibility for both directions, according to ACI Committee 436 (1966) are:

1.75/(.2091) = 8.37 for transverse direction

1.75/(.2146) = 8.16 for longitudinal direction.

The mat can be regarded as rigid in both directions since 8.37 is larger than the span of the ribs in the transverse direction (8.10 meters), and 8.16 times 1.20 = 9.79 is larger than the span of the ribs in the longitudinal direction (9.07 meters). The ACI Committee 436 (1966) permits a variation of 20% in the final values.

Structural Analysis

The conditions of equilibrium and geometrical compatibility of the entire mat were taken into consideration by means of a mathematical model that represented the grid formed by the orthogonal inverted ribs supported at the points of intersections with column axes. That model considered full structural interaction in the both senses between the orthogonal stiff beams.

To work out the design moments and shear forces of the elements of the grid, the spans of the inverted ribs were loaded with an upward load whose shape was a direct consequence of assuming a tributary area of load that results when 45° diagonal lines are drawn in the horizontal plane from the column centers at each rectangular panel between ribs. By this way the upward load has a triangular or trapezoidal form, whose maximum value is equal to the product of the height of the tributary load times the soil upward pressure. See Figs. 3, 4 and 5 with these upward loads.

In the computer output, the upward reactions of the grid at some of its nodes resulted larger than the column downward loads. This meant that the assumptions for the grid support were valid for these nodes, but insufficient grid support was provided at nodes where the upward reactions of the grid were lower than the downward loads of the columns.

In order to account for the insufficient support at the nodes where the grid upward reactions were smaller than the column downward loads, a new grid analysis was made, assuming the grid supported only at the nodes where the grid upward reactions were equal or larger than the column downward loads.

Each of the nodes with insufficient grid support was downward loaded with a load equal to the difference (in that node) between the bigger downward load and the lower upward reaction. In this second analysis no other loads were considered.

The structural elements of the mat were designed considering for the superposition of the results of the two analysis described before.

Nominal Pressures on the Soil

The total weight of the building without its foundation is about 29,100 metric tons (64,136 kips), being the weight of the mat itself about 4,400 metric tons (9,698 kips). With these values, the nominal uniform pressure transmitted to the soil is 30.56 metric tons per square meter (44 psi).

The maximum design overturning moment determined by the Venezuelan Seismic Code (1967) is for this building 48,390 meter x ton, (350,000 foot x kip) and occurs in the shortest dimension of the mat. (Transverse direction).

Fig. 7. Construction Joints - Longitudinal Ribs

When seismic requirements are considered, the nominal uniform pressure caused by the action of the vertical loads, changes to a maximum of 42.78 metric ton per sq. meter (61 psi) and a minimum of 18.34 metric ton per sq. meter (26 - psi). For this mat, a maximum nominal uniform pressure on the soil of 35 metric ton per sq. meter (50 psi) was permitted. The maximum value is lower than the nominal pressure permitted when seismic requirements are taken into account, which in this case is 35 x 1.33 = 46.55 metric ton per sq. meter (66 psi). For this reason the mat was designed for an upward uniform pressure of 35 metric ton per sq. meter (50 psi).

The design of the reinforced concrete elements were carried out according to the ACI Building Code (1971).

CONSTRUCTIONS PROVISIONS

The dimensions of the mat called for special specifications regarding the construction joints The concrete of the bottom slab .55 meters (22 inches) thick was poured in one continuous operation. The construction joints at the inverted longitudinal ribs were designed at the center of the spans using a shear-key of half depth of the transverse section of the rib. The Fig. 7 shows the executed joints of this type and the Fig. 6. shows the first and second concrete pour. All joints were construited using suitable forms.

Fig. 8. View of Complete Mat Foundation.

ACKNOWLEDGEMENTS

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