EARTHQUAKE DESIGN OF A 32-STORY A-SHAPE REINFORCED CONCRETE BUILDING

by

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SYNOPSIS

This paper describes the application of the new Venezuelan Seismic Code MOP-1967 (1), to the design of a 32-story reinforced concrete building with special features, such as inclined facade columns and end macroframes constituted by one story high beams placed at every fourth floor level. The result of a dynamic analysis performed in each direction of the structure and its adjustment to the Code requirements is discussed. Comparison was made between the base shears design values and the Structural Engineers Association of California (SEAOC-1968) regulations. See fig. 7 and 8.

STRUCTURAL DESCRIPTION OF THE BUILDING

The building (fig. 1), has a reinforced concrete structure and consists of 32 stories, two of which are below ground level and confined by retaining walls, while 30 floors are free to move laterally. A schematic floor plan is shown in fig. 2, and the variable shape of the building is evident in fig. 3, showing the macroframes on axes 1 and 6. The laterally resistant system differs on each direction due to the variable shape and the possible arrangements of the structural elements in the floor plan. In the East-West direction, the resisting system consists of frames A, B, C and D. Frames A and D (fig. 4), are contained in the inclined building facades. Their columns feature three-story unrestricted height above ground floor level, crowned by a large box girder placed at the third floor level. Frames B and C (fig. 5), contain a concrete shear wall between their central columns reaching up to one third of the building height, and then disappearing gradually to avoid a sudden stiffness change. Frames B' and C'support the mezzanines and reduce the large spans at the lower levels, they are of minor importance to the lateral building resistance. In the North-Scuth direction, the resistant system consists of frames 1 to 6, they support the one-way ribbed slab which runs East-West. The macroframes 1 and 6 (fig. 3) contain one story high beams at levels 3, 8, 13, 18 and 23 from the necessity of tying together the two flanges of the "H" shaped plan, while maintaining the architectural concept of large free lateral courts. Figure 6 shows frames 2 to 5, which are conventional frames with inclined exterior columns. At ground floor level, all North-South frames are post-tensioned across the base to absorb the horizontal component of the inclined column load. The post-tensioning force was introduced in steps as construction progressed. The building rests on large cast-in-place piles excavated with bentonite mud and anchored in a layer of dense gravel N(SPT) > 100, at a depth of 25 meters.

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SEISMIC ANALYSIS AND STRUCTURAL DESIGN

Seismic analysis was performed in compliance with the new Venezuelan Seismic Code MOP-1967 (1). The dynamic behavior of the structure was investigated in both directions, taking into account the variable shape and mass distribution of the building. As there exists no recorded major earthquake for Caracas, the North-South component of the El Centro 1940 earthquake was used, scaled down to a spectral acceleration of 0.2g. In the North-South direction, the first mode period was 1.05 sec., resulting in a total base shear of 0.055g. In the East-West direction, the first mode period was 1.53 sec., resulting in a total base shear of 0.041g. Seismic weight used in the analysis was 1.1 metric ton/m2 (Dead load + 25% Live load). Natural periods were verified by an accelerograph placed on the 27th floor of the complete structure. Results were remarkably close to the dynamic analysis, being 1.49 sec in the East-West direction and 1.0 sec in the North-South direction.

The Code (1) prescribes for this building a minimun total base shear of 0.042g (60% of 0.07g with triangular distribution). To comply with this condition, taking into account the dynamic response in each direction, the structure was designed with a total base shear of 0.05g in the East-West direction, and 0.067g in the North-South direction, each distributed along the building height in accordance with the corresponding response curve (See fig. 7 and 8). In practice this means that the building was designed for 1.22 times the dynamic response due to a spectral acceleration of 0.2g. As a comparison, the SEAOC-1968 code establishes for this building in the East-West direction (K= 0.8, T= 1.53 sec) a total base shear of 0.0347g, and for the North-South direction (K= 0.8, T= 1.05 sec) a total base shear of 0.0394g. These base shears represent 69%(East-West) and 59%(North-South) of the design values used. For design purposes, the acting lateral forces were distributed to each frame in both directions taking into account in-plan torsion and the stiffness of each frame. In the North-South direction each macroframe carries 30% of the total lateral load. In the East-West direction, frames B and C, containing the shear wall, carry each 34% of the total lateral load. Lateral deformation is kept below 0.2% between any two points along the vertical distance between them (Code requirement). All analysis included axial member deformation, the column inclination and the influence of actual member size by considering suitable infinitely rigid haunches at each joint.

ACKNOWLEDGMENT

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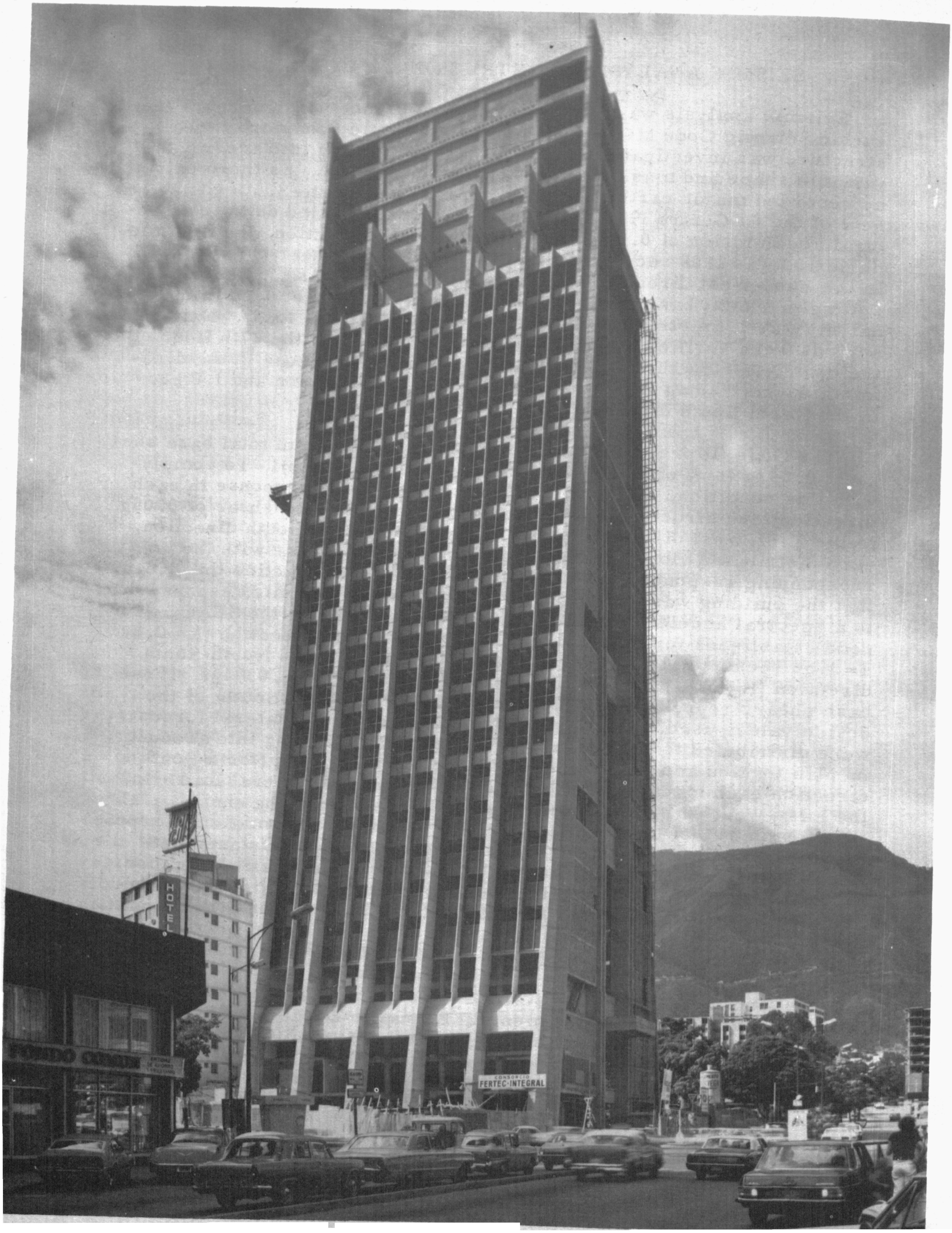

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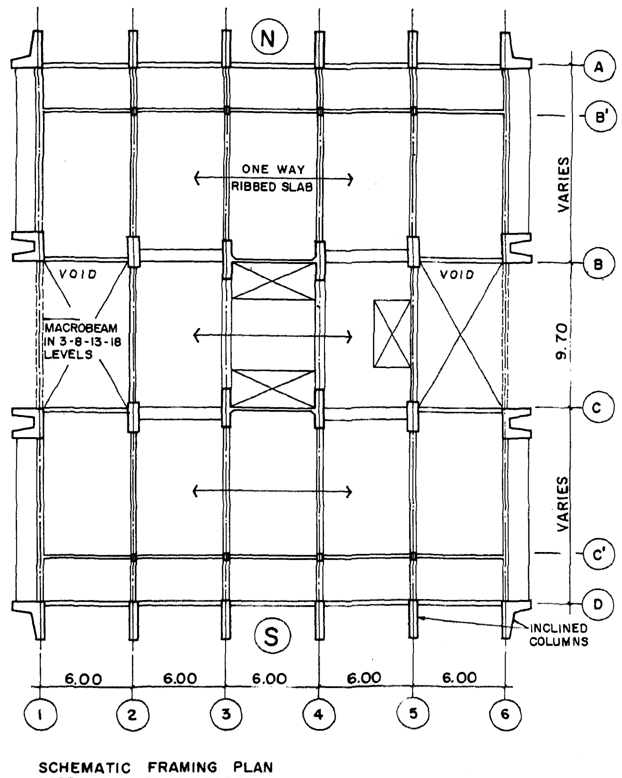

N
S
A
B'
B
C
C'
D
ONE WAY
RIBBED SLAB
VOID
VOID
MACROBEAM
IN 3-8-13-18
LEVELS
VARIES
9.70
VARIES
INCLINED
COLUMNS
6.00
6.00
6.00
6.00
6.00
1
2
3
4
5
6
SCHEMATIC FRAMING PLAN

FIG. 2

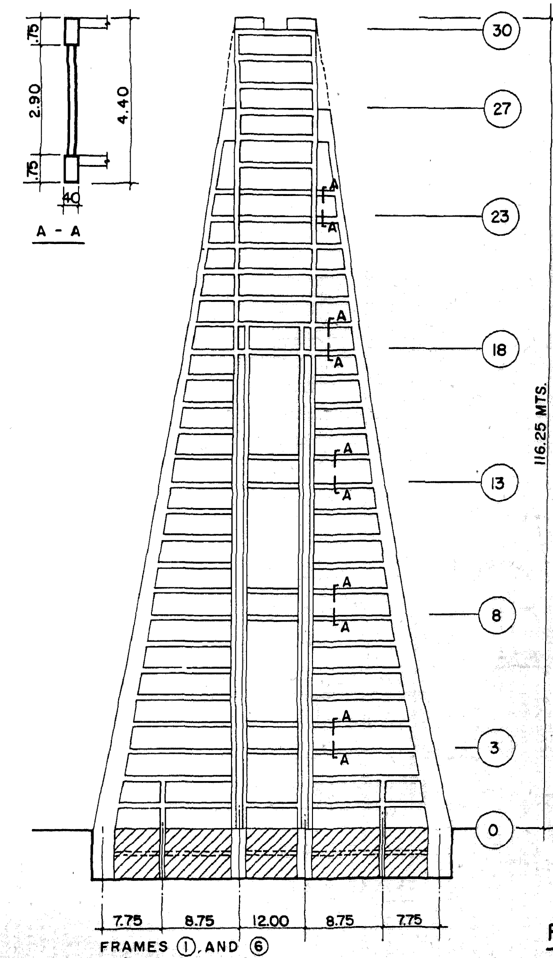

.75
2.90
.75
4.40
40
A - A
30
27
23
18
13
8
3
0
116.25 MTS.
7.75
8.75
12.00
8.75
7.75
FRAMES ①, AND ⑥

FIG. 3

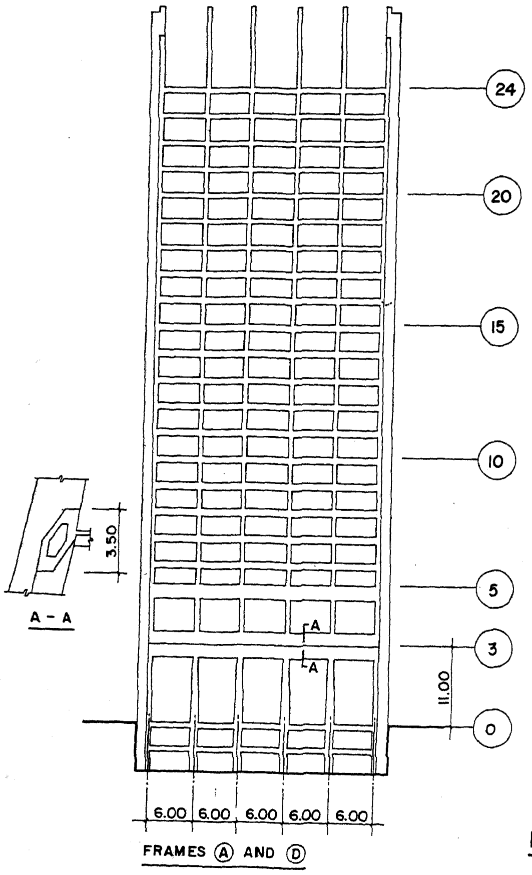

24
20
15
10
5
3
0
3.50
A - A
A
A
11.00
6.00 6.00 6.00 6.00 6.00
FRAMES Ⓐ AND Ⓓ

FIG. 4

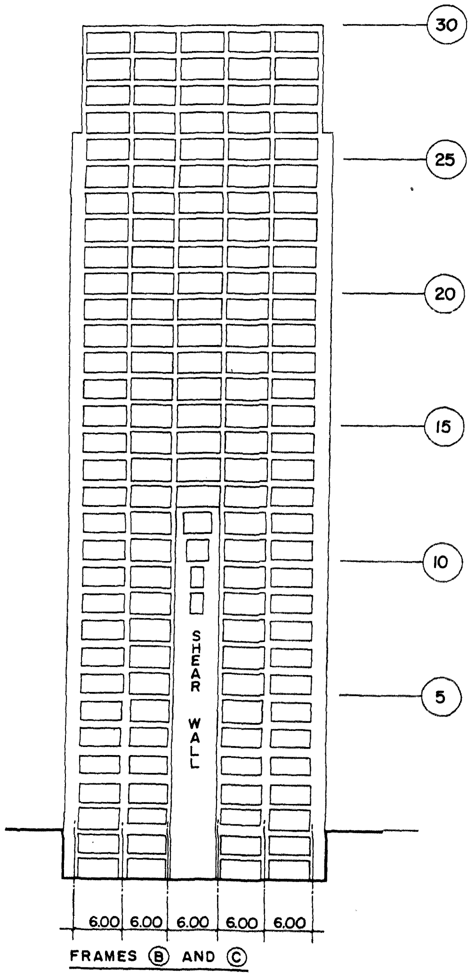

30
25
20
15
10
5
SHEAR WALL
6.00 6.00 6.00 6.00 6.00
FRAMES Ⓑ AND Ⓒ

FIG. 5

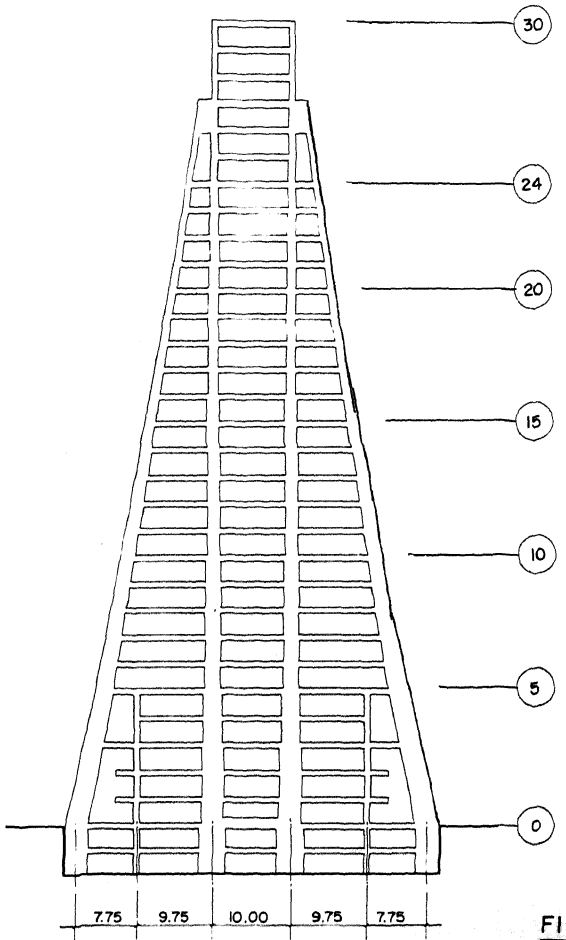
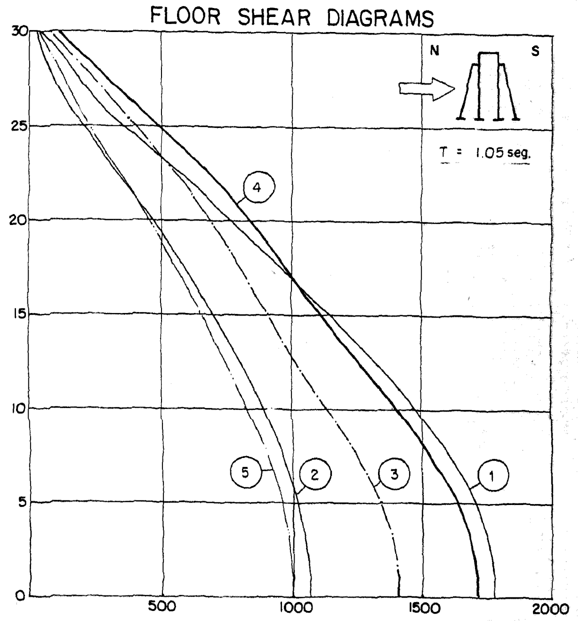


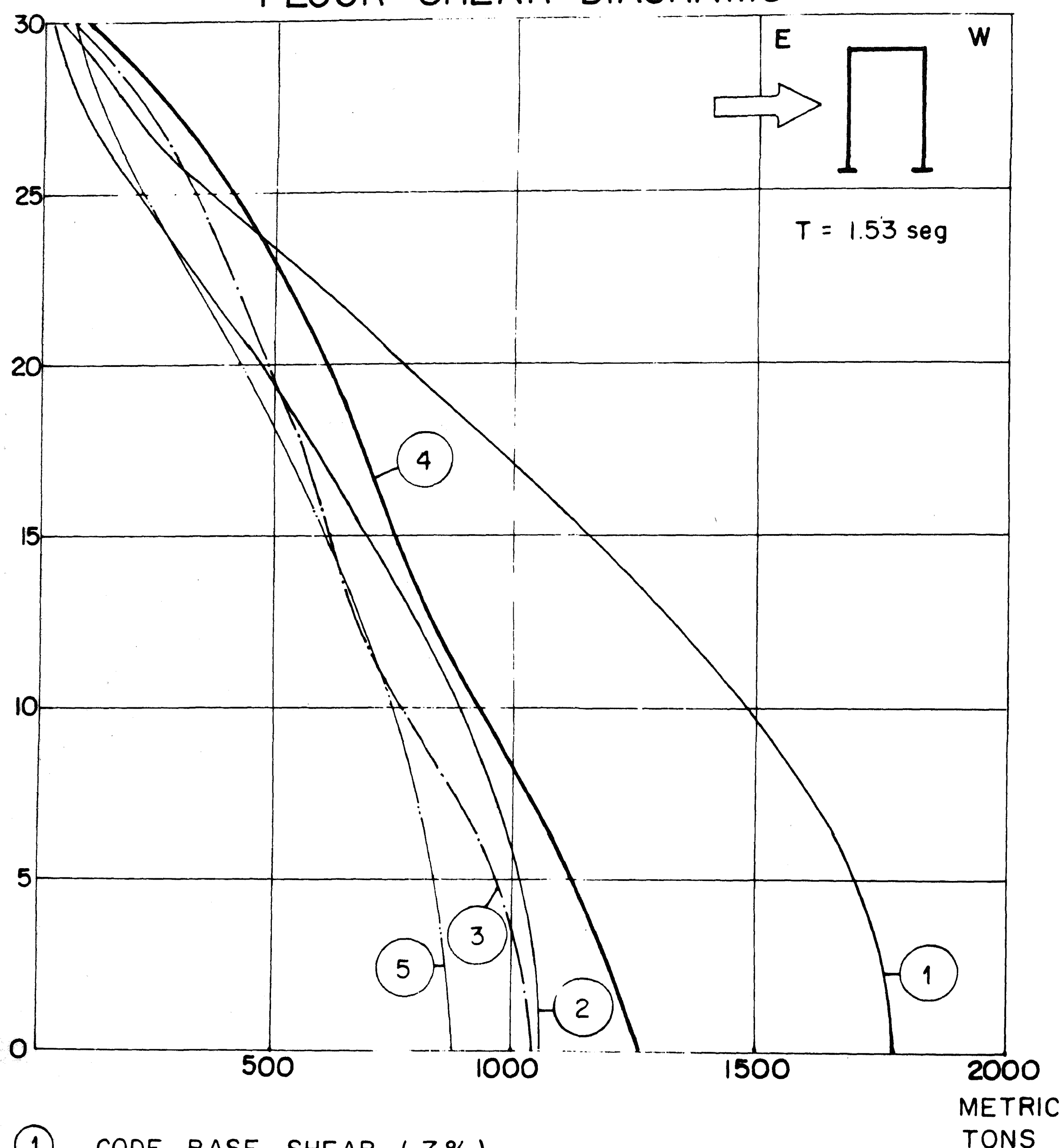
FIG. 6



① CODE BASE SHEAR (7%)
② 60% OF CURVE ① 4,2 %
③ DYNAMIC RESPONSE AT 0,2g (5,48%)
④ DESIGN VALUES (6,7%)
⑤ SEAOC CODE (1.968) BASE SHEAR (3,94 %)

FIG. 7

FLOOR SHEAR DIAGRAMS



① CODE BASE SHEAR (7 %)

② 60% OF CURVE ① 4,2 %

③ DYNAMIC RESPONSE AT 0,2g (4,1 %)

④ DESIGN VALUES (5 %)

⑤ SEAOC CODE (1.968) BASE SHEAR (3,47 %)

FIG. 8