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INFLUENCE OF SOIL-STRUCTURE INTERACTION ON DYNAMIC RESPONSE OF HIGH-RISE BUILDINGS IN MEXICO CITY DUE TO SEPTEMBER 19, 1985 EARTHQUAKE

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SUMMARY

The influence of soil-structure interaction on the dynamic response and damagibility of two types of high-rise buildings in the urban area of Nonoalco - Tlatelolco in Mexico City have been analyzed and presented in order to assess the effects of the earthquake of September 19, 1985, and to explore the influence of the structural and foundation improvement on the reduction of damagibility in future earthquakes. The strain dependent dynamic properties of Mexico City clays determined at the IZIIS laboratories in Skopje have been used for modelling of the soil-structure interaction and analysis of the dynamic response of the selected buildings.

INTRODUCTION

During the last two decades, natural disasters, and earthquakes in particular, have tended to become increasingly destructive as they affect ever larger concentration of population and material properties. Although significant efforts have been made for assessment of the seismic hazard and mitigation of its consequences, major earthquakes have continued to cause enormous damage to the economy of the affected regions and a large number of countries in the world. The most dramatic confirmation of the above statement is evident in Mexico City due to the September 19 and 20, 1985 earthquakes of magnitude 8.1 and 7.5, respectively, at a distance of 350 kilometers from the epicenter, producing material losses of about 4.5 billion dollars, including failure of more than 200 modern high-rise buildings (1,6).

On the basis of the given assignments by the authorities of the Department of the Federal District of Mexico and the tasks and duties determined by the Executive Council of SFR Yugoslavia, a Yugoslav Mission of Experts composed of 15 specialists, in close cooperation with the responsible authorities of the Federal District and specialized institutions and organizations from Mexico City, immediately after the earthquake, performed detailed classification of damage and usability of 102 residential and 56 public buildings in one of the most affected urban areas of Nonoalco - Tlatelolco with totally 293 structural units and total floor area of 1.13 milion square meters for about 100.000 inhabitants. It has been found out that 46% of the buildings were usable after easily repairable nonstructural damage, 42% with moderate damage but economically justified for repair, 9% with heavy structural or foundation structure damage, for which decision for demolition or repair could by made after detailed structural and economic analysis, and 3% of collapsed or demolished buildings.

Within six months at IZIIS in Skopje detailed analysis and synthesis of soil conditions, recorded earthquake ground motions (6, 2, 3, 4, 5) and expected seismic hazard levels have been carried out for the valley of Mexico City, considering in particular the urban area of Nonoalco - Tlatelolco. Based on determined criteria, expected earthquake ground motions and performed dynamic testing of Mexico City clays (6.4), detailed modelling and dynamic linear and nonlinear response analysis for 5 selected structural types of dominantly present residential buildings, for existing and improved structural and foundation system, have been performed in order to make assessment of the earthquake effects and to recommend measures for repair and strengthening of the buildings. Type M, of 22 storeys, and type C, of 14 storeys buildings are discussed and presented with sufficient details in order to assess effects of the foundation and structural improvement on the dynamic response and damagibility of the selected buildings (6.2, 6.3).

BEHAVIOUR OF EXISTING AND IMPROVED STRUCTURAL SYSTEMS

The most significant influence to the structural behaviour of the buildings in the northern part of Mexico City and within this in the urban area of Nonoalco - Tlatelolco is dominated by the specific soil deposits of soft clays in the upper 25 to 30 meters and consequently by specific modification of the induced earthquake ground motions. Due to this, particular attention has been paid to establish by laboratory testing more reliable dynamic properties of the soft clay deposits (6.4) and to compare them with the available data from Mexico City (4) and other regions on soft clay deposits (3). Strain dependent shear moduli and damping coefficients obtained from six series of tests performed at IZIIS, Skopje on samples taken in Nonoalco -Tlatelolco (Figs 1 and 2) are presented as average values for different depths and compared with other available data. These dynamic properties have been used for modelling and analysis of the soil-structure interaction and modification of earthquake ground motions.

For the purpose of analyzing the effects of the September 15, 1985 earthquake on existing buildings of type C (Fig. 6) which suffered extensive damage and failure of limited number of structural units, and type M (Fig. 3) suffering intensive inclination, have been analyzed with modelling three different depths of existing (6.8 m and 4.0 m) and improved foundation (Fig. 4). Further, in order to reduce relative displacements and to assure continuity in the supper structure additional structural elements are implemented. All the considered existing and improved structural and combined foundation systems have been analyzed to the reduced SCT1 earthquake record and the seismic forces required by the Seismic Design Code of Mexico City. The results of principal relevant parameters for comparison of dynamic response and damagibility levels are presented for both structural types in Tables 1 and 2. Comparing the values of the inter-storey drift index of the existing structural systems in both orthogonal directions it is evident that they are several times larger than those which could be accepted (6-7‰) for R.C. buildings in order that structural and mainly nonstructural damage be economically justified. With the improvement of the foundation structure with most favourable depth (Fig. 4) and super structure of both structural types (Figs 3 and 5) significant reduction in the induced seismic forces is achieved, and consequently reduction in the inter-storey drifts to the acceptable damagibility level, compared with that experienced in the earthquake of September 19, 1985.

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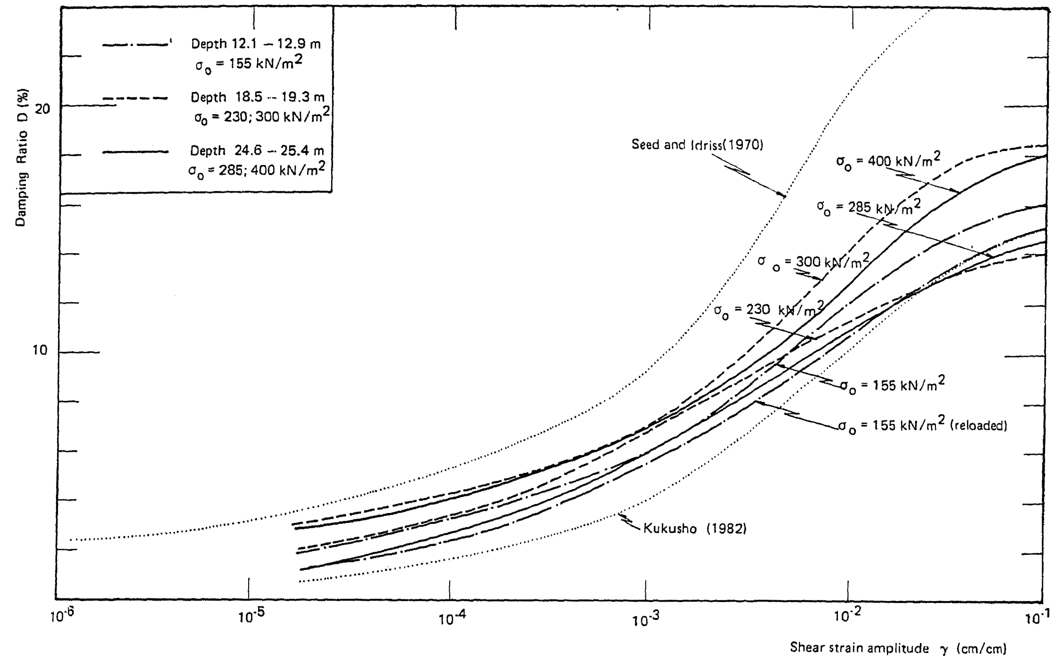

Fig. 1. Strain Dependent Damping Ratio, Cumulative Comparative Presentation of IZIIS Tests

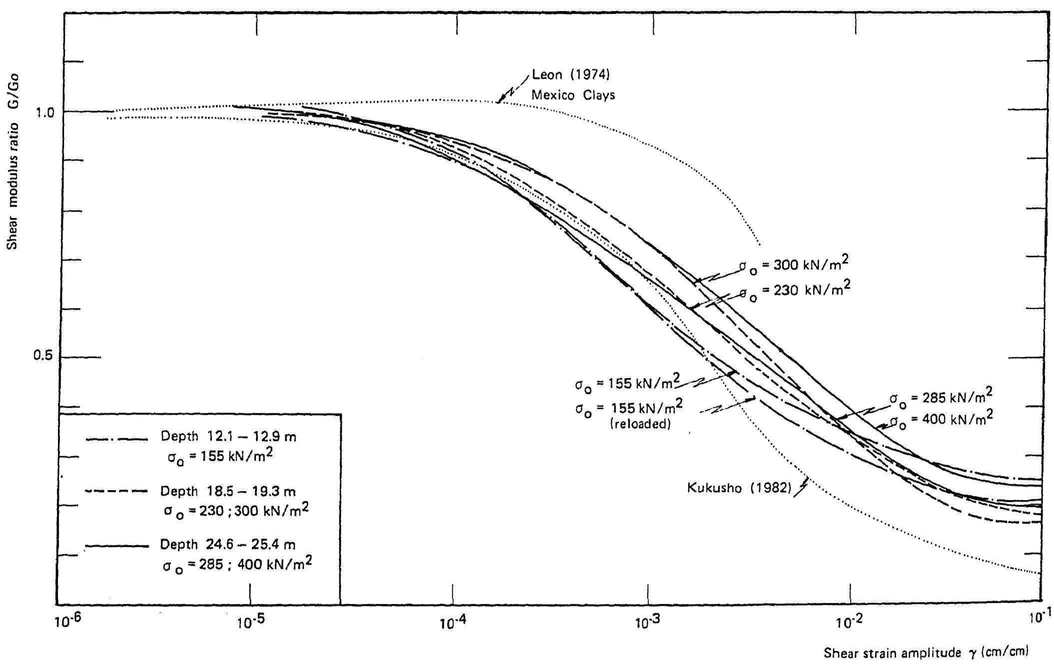

Fig. 2. Strain - Dependent Shear Moduli Cumulative Comparative Presentation of IZIIS Tests

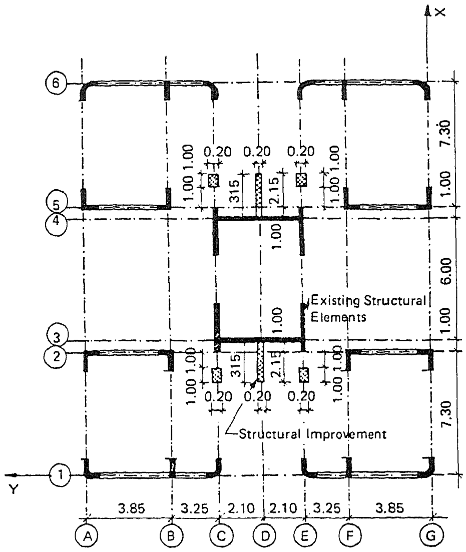

Fig. 3. Plan of Typical Floor from Level 11 to 21 of 22 Story Building - Type M, Tlatelolco, Mexico D.F.

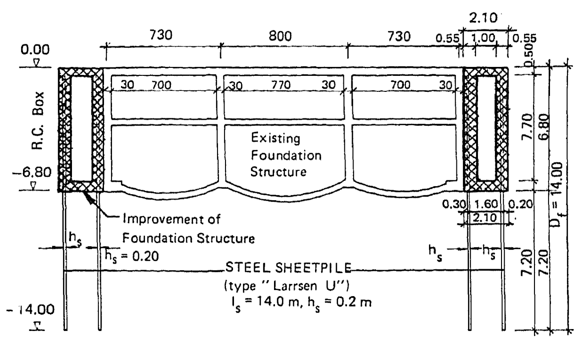

Fig. 4. Cross - Section of the Existing and Improved Foundation Structure, Type M, Tlatelolco, Mexico D.F.

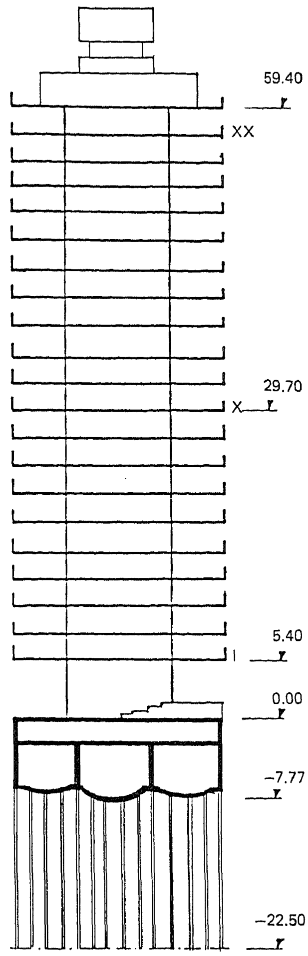

Fig. 5. Scheme of the Cross Section of 22 Story Building - Type M, Tlatelolco, Mexico D.F.

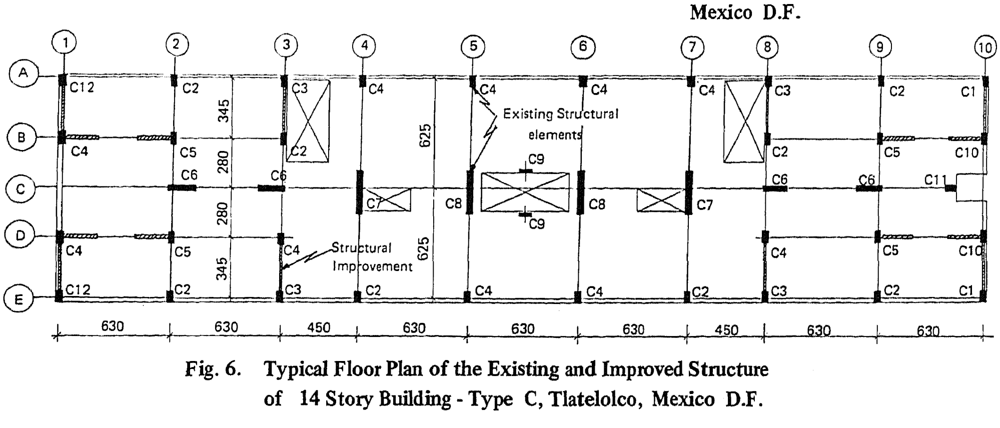

Fig. 6. Typical Floor Plan of the Existing and Improved Structure of 14 Story Building - Type C, Tlatelolco, Mexico D.F.

Table 1. Dynamic Response Characteristics of 22 Story Building - Type M, Tlatelolco, Mexico D.F. for Different Depths of Foundation Embeddement

Foundation Depth (m)	Shear Base Coefficient C_b (%)		Period of Vibration T_1 (s)		Rotation Θ (rad) ($\times 10^{-2}$)		Absolute Displacement δ_{max} (cm)		Maximum relative Displacement (cm)		Interstory Drift ($\times 10^{-3}$)	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Existing Structural System to Reduced SCT – 1 Earthquake Record												
6.8 m	11.2	20.3	2.97	2.40	0.154	0.226	55.3	58.9	3.2	2.9	11.8	10.7
14.0 m	17.0	19.0	2.75	2.14	0.123	0.126	68.8	48.3	4.2	2.7	15.6	10.0
22.5 m	23.0	26.0	2.63	1.99	0.048	0.052	79.3	52.5	5.0	3.0	18.5	11.1
Improved Structural System to Reduced SCT – 1 Earthquake Record												
6.8 m	22.3	-	2.62	-	0.269	-	73.6	-	3.9	-	14.4	-
14.0 m	19.9	-	2.36	-	0.137	-	56.4	-	3.3	-	12.2	-
22.5 m	27.2	-	2.09	-	0.0136	-	59.2	-	3.6	-	13.3	-
Improved Structural System to the Requirements of Seismic Design Code (Mexico D.F.)												
6.8 m	11.5	11.7*	2.62	2.40*	0.124	0.116*	33.6	30.0*	1.8	1.5*	6.7	5.6*
14.0 m	10.6	10.7*	2.37	2.14*	0.0689	0.0647*	27.4	23.8*	1.62	1.3*	6.0	4.8*
22.5 m	10.4	10.5*	2.22	1.99*	0.0212	0.0207*	23.9	20.6*	1.49	1.2*	5.5	4.4*

Table 2. Dynamic Response Characteristics of 14 Story Building - Type C, Tlatelolco, Mexico D.F. for Different Depths of Foundation Embeddement

Foundation Depth (m)	Shear Base Coefficient C_b (%)		Period of Vibration T_1 (s)		Rotation Θ (rad) ($\times 10^{-2}$)		Absolute Displacement δ_{max} (cm)		Maximum relative Displacement (cm)		Interstory Drift ($\times 10^{-3}$)	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Existing Structural System to Reducted SCT – 1 Earthquake Record												
4.0 m	20.3	22.9	1.71	2.33	0.0085	0.624	22.4	54.0	1.4	3.7	5.2	13.7
Improved Structural System to Reduced SCT – 1 Earthquake Record												
4.0 m	18.2	22.7	1.87	2.16	0.222	0.474	23.7	42.8	1.4	2.8	5.2	10.4
14.0 m	10.6	10.5	1.37	1.28	0.068	0.0047	8.34	7.45	0.65	0.66	2.4	2.4
19.2 m	9.9	10.2	1.29	1.31	0.0256	0.0002	5.81	7.01	0.5	0.63	1.8	2.3
Improved Structural System to the Requirements of Seismic Design Code (Mexico D.F.)												
4.0 m	12.3	12.1	1.87	2.16	0.157	0.254	16.8	23.0	1.0	1.5	3.7	5.6
14.0 m	10.9	10.6	1.37	1.28	0.0752	0.0263	9.64	9.72	0.77	0.84	2.8	3.1
19.2 m	10.8	10.5	1.29	1.31	0.0532	0.0111	8.56	8.94	0.71	0.8	2.6	3.0