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SHAKING TABLE TEST OF 1/11 SCALE MODEL OF TREASURY BUILDING IN ALMA ATA, KAZAKHSTAN

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ABSTRACT

The Treasury Building in Alma Ata in the Republic of Kazakhstan is located within a very high seismicity zone, with expected earthquakes at a distance of 30 km with magnitudes close to 8.0 degrees. The building consists of a treasury part, considered as a special structure, which must behave in linear range even under maximum earthquakes, while the other part of the building may experience earthquake damage but not failure.

Respecting these design criteria, the geometry of the structural system and seismic shaking table characteristics, a physical model in 1/11 scale has been designed. The testing showed that for the design earthquake the physical model structure was at the limit of the elastic behaviour, while for the maximum probable earthquake it suffered structural damage, mainly to the part and points as expected by the design.

In addition to the verification of the design criteria for the global behaviour of the considered structure, this testing demonstrates that by correct physical modelling and adequate testing very useful data for definition of the seismic stability of the tested structure can be obtained.

KEY WORDS

Physical modelling, experimental testing, shaking table testing, RC physical models

INTRODUCTION

According to the world practice, testing of physical models of civil engineering structures using seismic shaking table systems is being conducted with various purposes. Besides the purpose for performing functional research in earthquake engineering, a significant number of shaking table tests of models of real structures are performed for studying the overall structural behaviour of complex or important structures located within seismic-prone areas. In most cases, these studies are conducted during the design of the structure.

Presented in this paper is only a small part of the experimental results for definition of the overall dynamic behaviour of the Treasury Building in Alma Ata in the Republic of Kazakhstan. The Building has been designed and is under construction by the company of EIC Management of Oberhausen, Germany. The seismic activity of the city of Alma Ata is very high with an occurred earthquake of M ≅ 8,0 at a distance of 30 km from the site of the Building. The performed site investigations define the design parameters of the maximum expected acceleration of 0.8 g PGA, in horizontal, and 0.4 g in vertical direction, respectively. The seismologists of Alma Ata defined four artificial earthquake time histories, which have been applied both for the design of the structure and for the testing of the model. Two time histories have a predominant acceleration in frequency domain of 0.8 - 2.6 Hz, while the other two, between 2.0 - 4.0 Hz.

The importance of the Building defines also the design seismic safety criteria. So, in the case of a maximum probable earthquake the treasure part should remain in elastic range, while the upper structure may suffer certain structural damage but not failure.

The physical model respects the design values, and testing is conducted by simulation of the design seismic input. The dynamic hehaviour of the physical model showed good correlation with the design dynamic behaviour, especially through the occurrence of mechanisms of nonlinear deformations and controlled damage to the structure. Namely, by the design criteria of the integral Building, it has been accepted that the treasure part be designed so that, under maximum probable earthquake, it remains in elastic range, while the remaining part of the Building may suffer structural damage but not failure. This structural concept was verified by seismic shaking table testing of the physical model, by simulating the same acceleration time histories as those used for the design.

DESCRIPTION OF PROTOTYPE BUILDING

The Treasure Building has three stories, out of which the first two have an approximate area of 57.0 x 57.0 m, while the upper three, 48.0 x 48.0 m, or a total area of about 14.00.00 square meters. Fig. 1 shows the cross section, with the position of the treasure part of the structure. The Building is constructed of reinforced concrete with compression strength of 30.0 and 55.0 MPa and it is founded on RC plate with a thickness of 103.0 cm.. For technological and safety needs the treasury part of the Building is structurally disattached from the remaining part of the structure.

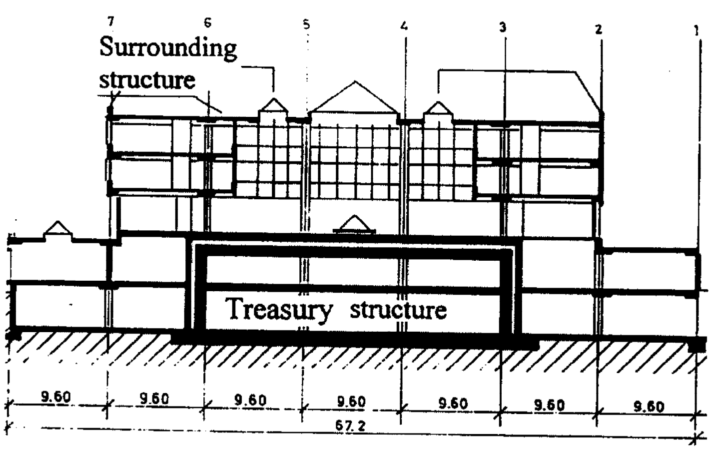

Fig. 1 Cross section of the prototype structure

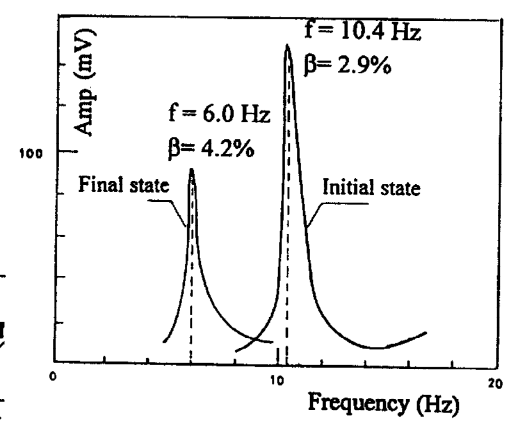

Fig. 4 Frequency response curves of the model identified at the beginning at the end of the testing

The structural system of the treasury part consists of RC walls, while the other part is with four corner staircase cores (J1, J2, J3, J4), (Fig. 2) and RC columns with RC floor slabs. The beams are incorporated in the floor slab, so that it can be globally said that the structural system consists of columns and floor slabs without beams (except at several positions). The top floor slab of the treasury structure and the floor slab of the upper structure are separated by a 50 cm space. To transmit the gravity loads from the super structure to the treasury structure, bearing joints capable of transmitting only gravity loads are designed, and the upper structure can relatively move in both horizontal directions with respect to the treasury structure. This is ensured by applying "Teflon" bearing joints, enabling sliding of the upper structure in both horizontal directions.

PHYSICAL MODEL

The model design is carried out on the basis of the design documentation of the prototype structure, applying the similitude theory based on the Buckingham theorem. The determination of the scales of the separate physical values of the model and the prototype is a rather complex process. Usually, these scales are inter-dependent.

In this case, the length scale depended on the proportions and the capacity of the seismic shaking table for testing of the model. Considering that the size of the seismic shaking table is 5.0 x 5.0 and its bearing capacity is 40 t, the accepted length scale is l_r = 1/11. The scales of the other physical values, considered relevant for the design of the physical model are shown in Table 1.

Table 1. Scaling factors

Parameters of similitude	Required scaling factor	Achieved scaling factor
Length (l_r)	1/11	1/11
Time (t_r)	$(1/11)^{1/2}$	$(1/11)^{1/2}$
Frequency (f_r)	$(11)^{1/2}$	$(11)^{1/2}$
Gravity acceleration (g_r)	1	1
Acceleration (a_r)	1	1
Young's modulus (E_r)	1/11	1/20 (1/25)
Mass density (ρ_r)	1	1/1.14
Added mass (m_r)	0	1/4.3
Stress (σ_r)	1/11	1/15 (1/17.5)
Force (F_r)	$(1/11)^3$	$(1/11)^3$
Displacement (δ_r)	1/11	1/11

Table 2. Prototype/Model parameters

PARAMETERS		Prototipe	Model
Number of levels		5	5
Dimension at base (m)		67.2/67.2	4.9/4.9
Hight of the structure (m)		24.86	2.26
Mass density (kN/m^3)		25.0	22.0
Compression strength (MPa)	MB 30	30.0	2.0
	MB 55	55.0	2.0
Young's modulus (MPa)	MB 30	32500.0	1600.0
	MB 55	39500.0	1600.0

On the basis of the scaling factor of the physical values between the prototype and the model presented in Table 1 and the chosen material for building of the model, the design parameters for the model have been defined. The physical values referring to the prototype, i.e., the model are shown in Table 2.

The model with size of the plan 4.9 x 4.9 m is placed on the RC slab (5.0 x 5.0 m). The height of the model is 2.26 m. The model has five floor levels out of which the lower two levels house the treasury. The principal structural elements of the model are vertical walls and columns as well as horizontal floor slabs of various thickness. The weight of the model is 13.3 t, while the weight of the reinforced concrete slab which it is placed on is 18.7 t, that makes a total of 32.0 t. Presented in Fig. 2 is the plan and the characteristic cross section of the model.

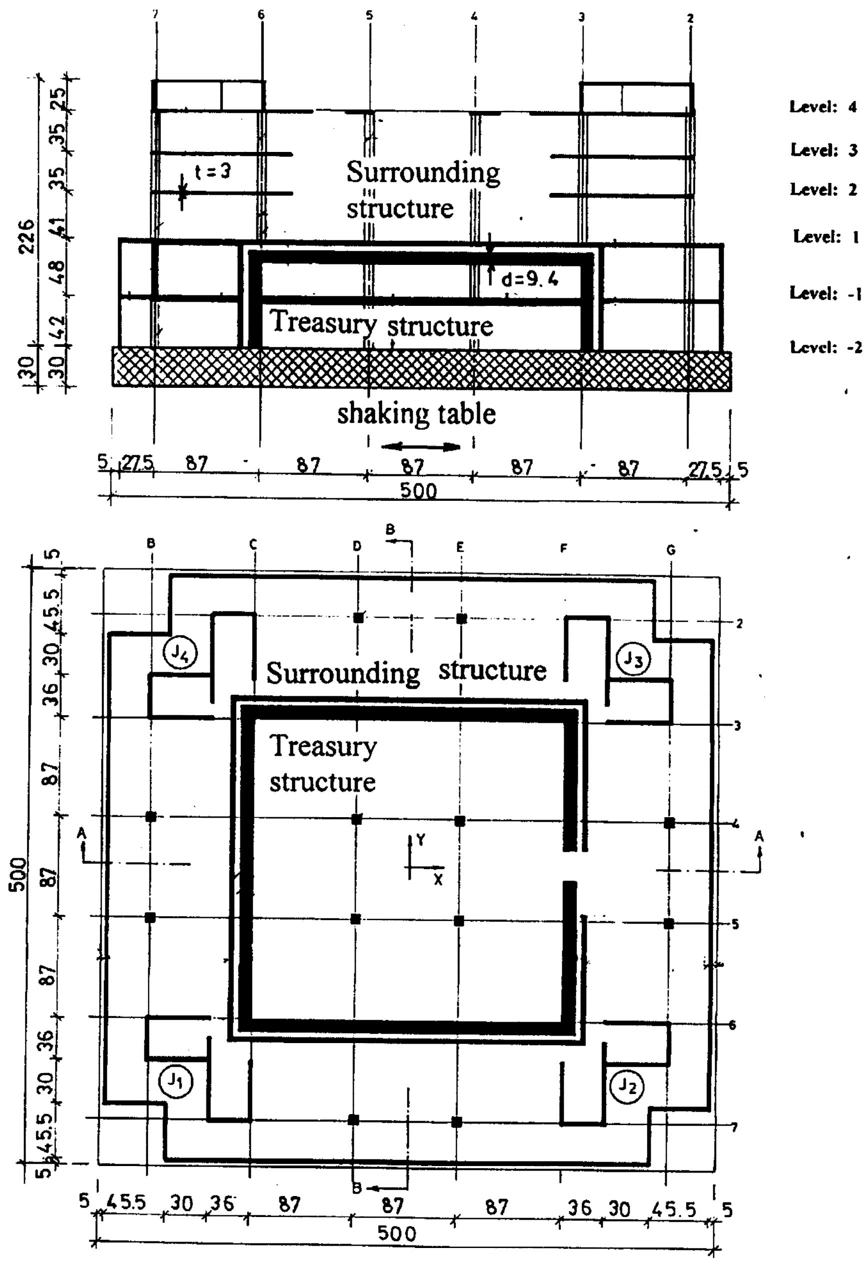

Fig. 2 Plan and cross section of the model

Composite material of gypsum, lead powder, diatomite, sand and water, mixed in determined proportions is used for building of the model. It is characterized by low strength, E = 1600 MPa and material density, γ = 22.0 kN/m^3.

PERFORMED EXPERIMENTAL TESTS

The model testing of the Building is conducted in compliance with the previously defined testing programme, which includes:

- Determination of the dynamic characteristics of the model;
- Definition of the response of the model to the selected seismic excitations using seismic shaking table for design and maximum probable earthquake;
- Determination of failure mechanisms.

The determination of the dynamic characteristics of the model (resonance frequencies, mode shapes and corresponding damping coefficients) is carried out applying several methods: ambient vibration, impulse test, random vibrations, forced vibration. This testing is performed at the beginning of the investigations, for definition of the initial state of the model, and at the end of the investigation, after the seismic excitation tests, when the model had suffered considerable damage.

In the second experimental phase, it was performed definition of the dynamic response of the model for the effect of selected seismic excitations, characteristic for the site on which the Building is being constructed, and adequately scaled to comply with the performed model analysis. Presented in Fig. 3 are the acceleration time histories of the seismic excitations applied during the testing of the model.

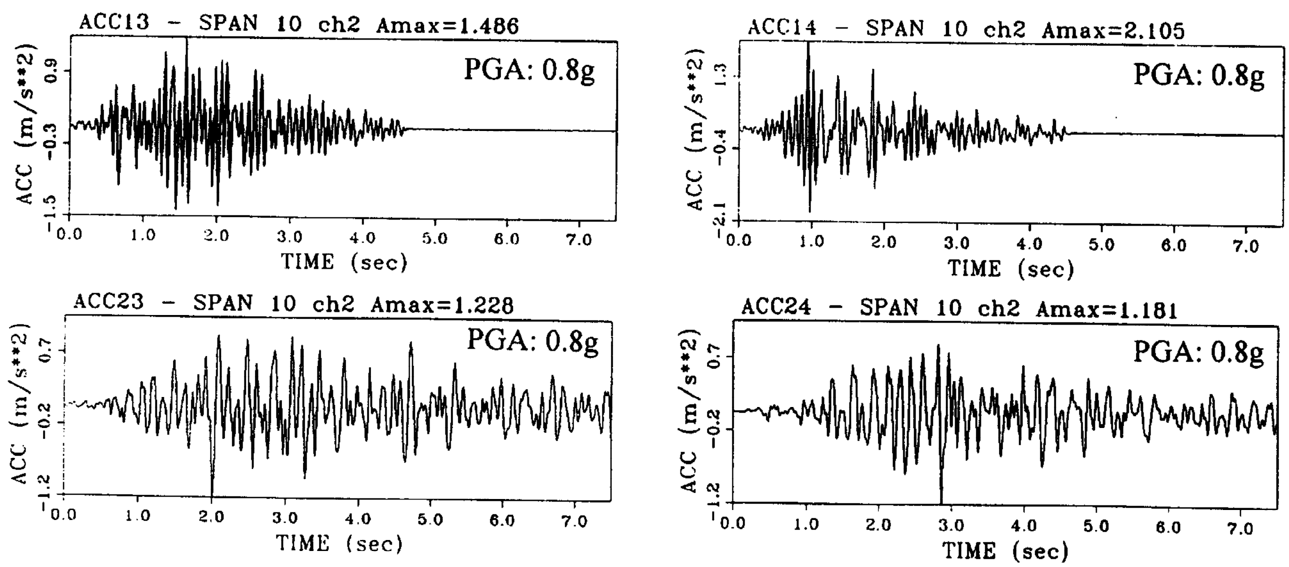

Fig. 3 Four different types of synthetic accelerograms used for earthquake simulation an the shaking table

Besides the performed series of linear tests, by simulating different levels of four time histories, the time history to which the model is most sensitive has been determined. The following tests on the model for nonlinear range of stresses and deformations have been performed:

- Excitations with an intensity of 0.25 g of PGA, causing no damage to the model. Four time histories are generated (A13, A14, A23, A24)
- Excitations with an intensity of 0.50 g of PGA - design earthquake due to which some slight damage to the structure have been recorded for all the four time histories;
- Excitations with an intensity of 0.80 g of PGA - earthquake due to which considerable damage to the structural system, but not failure, is allowed (maximum probable earthquake). This state is simulated applying A23 time history.

During the model testing, the dynamic response of the model was recorded by a 32 channel data acquisition system connected to a computer system VAXLAB model 4000-200. During the testing, the acceleration, displacement and strain response of the model at several characteristic points was measured. The seismic excitations of the model were generated using two-component seismic shaking table.

EXPERIMENTAL RESULTS

The resonance frequencies of the Building model are defined applying several procedures. The fundamental mode resonance frequency of the model in "X-X" direction was f = 10.4 Hz, in the beginning, while at the end of the testing, f = 6.0 Hz (Fig. 4).

The viscous damping coefficient of the model determined at the beginning of the testing was 2.9% of critical, while at the end, 4.2%. The values of the defined resonance frequencies of the model, determined applying different procedures before and at the end of the testing are shown in Table 3. The same Table shows also the corresponding viscous damping coefficients of the model.

Table 3. Resonance frequencies and corresponding damping coefficients of the model before and at the end of testing

Excitation	Initial state		Final state	
	Frequency (Hz)	Damping (%)	Frequency (Hz)	Damping (%)
Ambient Vibration	10.0	3.5	8.2	3.0
Impulse	10.8	2.0	6.8	6.1
Random	9.8	-	-	-
Force Vibration	10.4	2.9	6.0	4.2

Presented in Fig. 5 are the dynamic response of the model, acceleration, due to the effect of seismic excitations with intensities of 0.5 g and 0.8 g of PGA, respectively.

The results obtained by these investigations have shown that for excitations up to 0.25 g, including this level, no damage to the model was observed. The initial damage, in turns of horizontal and diagonal cracks to the transition part of the model from the lower, relatively stiff, to the upper, flexible, structure occurred during the 0.50 g intensity test. Damage occurred to the contact between the staircase cores and the horizontal slab at level "1". During the 0.80 g test, new damage occurred mainly concentrated to the staircase cores J1 and J2 in terms of partial falling off material. Initial damage was also observed to columns C6, D6, E6 and E7, which were at the side of the staircase cores J1 and J2. During the last, 1.00 g intensity excitation, that is not important for the model, heavy damage to the model with partial failure of cores J1 and J2 as well as intensive damage to the already damaged columns occurred.

The global behaviour of the physical model for generating of time histories shows correlation with the design state of the structure. In the case of the design earthquake, initial cracks to the model occurred, which is required by the testing programme, while for the maximum probable earthquake, considerable damage occurred to the four cores (J1, J2, J3, J4) at the level above the treasury part. Due to this earthquake, damage occurred neither to the treasury structure nor around it, which means that this important part of the structure remained linear. Such a global behaviour of the model verifies the adopted criteria for providing seismic safety of the Building, which although represents a whole, its exploitation importance is of two levels; i.e., the treasury part is of the first, and the remaining part of second category. Such cases are infrequent in practice.

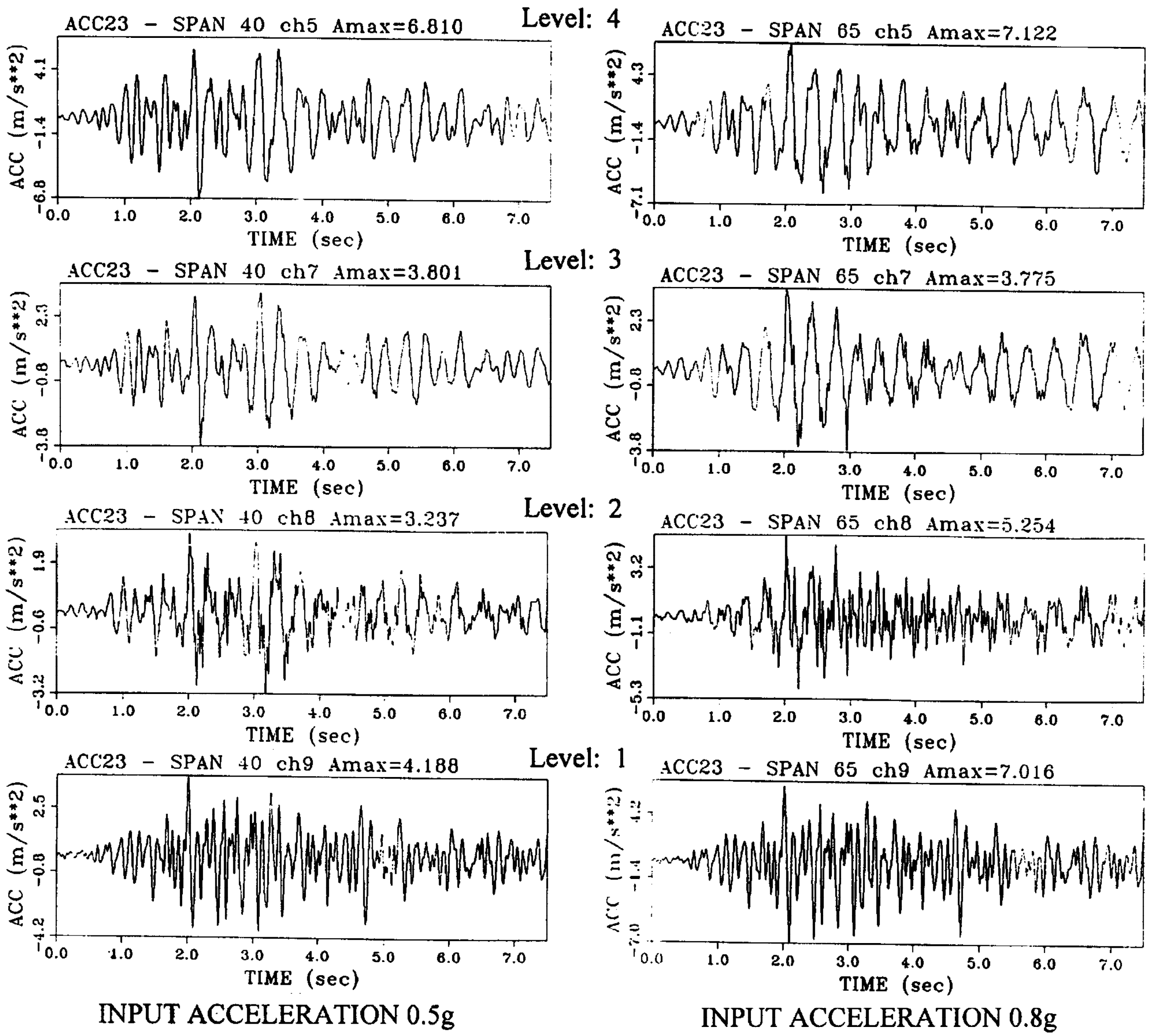

Fig. 5. Dynamic response of model acceleration due to seismic excitations of 0.5g and 0.8g of peak input acceleration for Acc 23 earthquake time history

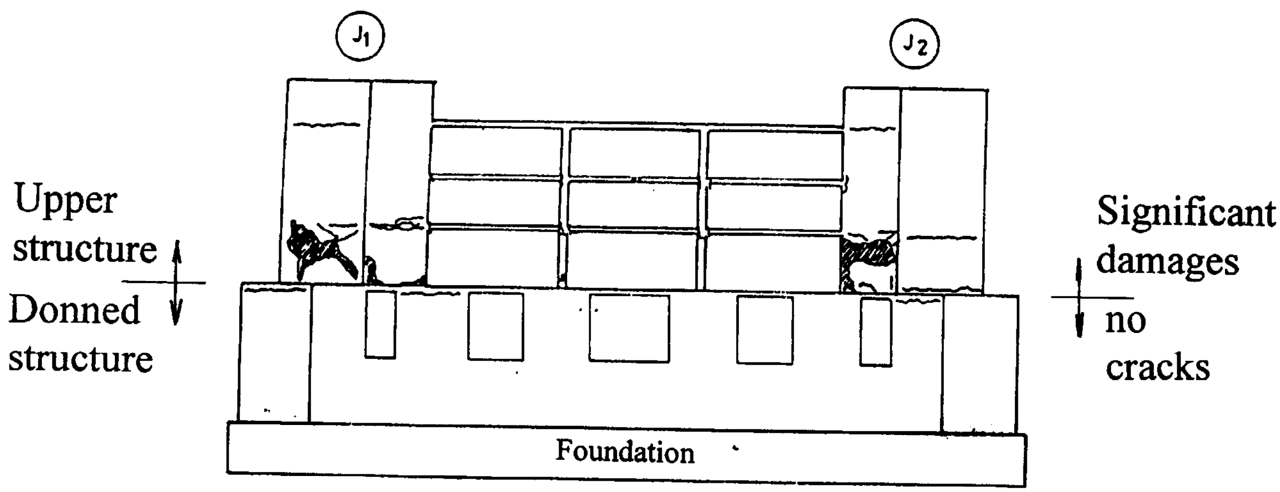

Fig. 6 Scheme of model damage

CONCLUSIONS

The Treasury Building in Alma Ata, in general, is very complicated for physical modelling; it has a large area in plan, large mass, unusual structural system, two levels of structural importance and very high seismic input. The experimental results have shown that even in such cases the physical modelling, if performed correctly, could provide useful information.

The design criteria for providing seismic safety of the building have been proved by testing of the physical model. For the design earthquake, only minor cracks occurred, while for the maximum expected earthquake, the locations and the size of damages to the structure were in accordance with the structural design criteria.

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