A new method of base isolation against earthquake damage using natural material

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1. INTRODUCTION

Structures, especially structures of reactors and the equipment in those structures, in earthquake-endangered areas should be protected from failure caused by subsoil vibration. Structure subsoil-isolation can be used ingeniously to achieve this aim, especially for low and middle-rise buildings. In this paper, a new isolation method using soil-liquefaction is studied.

Generally speaking soil-liquefaction is almost always a catastrophe during earthquakes, because the liquefied soil is squeezed out of its original place under the foundation of the building and the foundation looses its stability and bearing capacity. This gives rise to very large settlement and tilting of the building. However, if the volume of the soil is kept constant, the foundation failure will be avoided. Due to the reduction of the stiffness of the soil after liquefaction, the transmission of the subsoil vibration into the superstructures will be greatly decreased. There are examples of cases, in which buildings survived earthquake attacks under natural ground conditions. One of them was in Japan /1/.

2. A NEW ISOLATION METHOD AND ITS CHARACTERS

Based on the above-mentioned idea, a new isolation method is being developed. The construction of the structure subsoil-isolation system using this method is shown in Fig. 1: the superstructure is built on several isolators, which separate it from the subsoil. The isolators are composed of a layer of artificially selected and mixed soil, the relative density (symbol Dr) of which is low. Around the soil is an impermeable and elastic wall keeping its volume constant. Through a network of pipes, the soil in the isolators is constantly water-saturated.

How this system functions and how it satisfies the specifications of structure-base isolation, can be explained on the basis of what we know about soil-liquefaction and base-isolation:
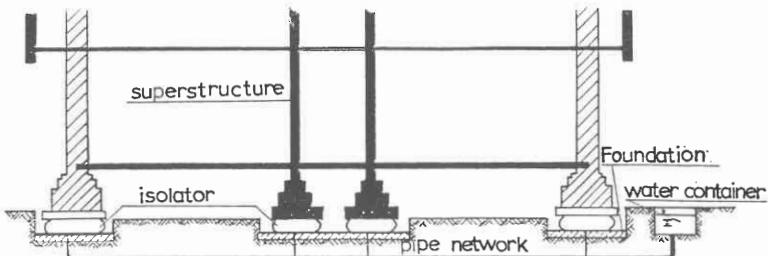
Fig. 1 Construction of the isolation system

a) The vibration energy input into the structure should be limited to an amount which does not lead to any structural damage. As we know from the results of soil experiments /2/, a loose, non-cohesive and saturated soil will liquefy after a number of shear loading cycles. The number of loading cycles to liquefaction depends on the soil density and the loading intensity (Fig. 2). To put it more exactly: the higher the loading intensity and the lower the soil density, the less is the number of loading cycles to liquefaction. That means that the vibration energy input in the soil till liquefaction will be confined. Accordingly, the energy transmitted into the superstructure before the soil liquefies will be limited too. The soil mixture and its relative density in the isolator will be selected so that the soil liquefies in a strong earthquake before the transmitted vibration energy can cause any structural damage.
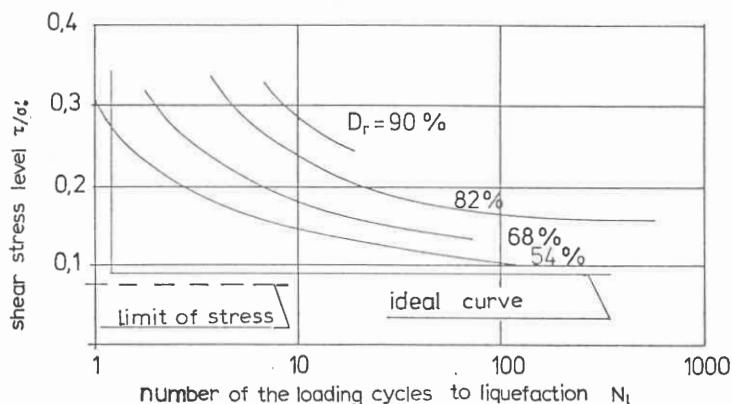

Fig. 2 Shear stress vs loading cycles to liquefaction

After the liquefied soil layer in isolators has lost its stiffness, the eigenfrequency of the isolated building will be shifted to a very low range, and thereby out of the most damaging frequency range of most earthquakes. Consequently, there will be no strong response of the building under further earthquake load, after the soil in the isolators has liquefied in the first cycles.

b) In any case, an isolation system should support the superstructure stably. This is ensured by the new isolation system. By virtue of an

impermeable and elastic wall, the volume and the height of the isolator will not change. Therefore the settlement and tilting of the building above the isolators will not happen. Besides, instead of the soil grain the pore water will support the structure.

c) A structure subsoil-isolation system should be rigid enough to supply the superstructure stable resistance to attacks of everyday's ambient cyclic loading which is not dangerous to buildings. It is known that there is a limit of shear stress in the soil, under which liquefaction does not take place inspite of an almost unlimited number of loading cycles (Fig. 2). Construction parameters of the isolation system can be regulated so that the limit of shear stress is larger than the amplitude of the above-mentioned loading in soil layer. If the soil liqufies after only one or two loading cycles under a dangerous shear-load from an earthquake, this behavior of soil will be ideal for the isolation purpose (Fig 2, ideal curve).

d) Isolators should have a large damping coefficient to provide the isolated structure with an energy-absorbing capacity. The soil after liquefaction is a good damping material owing to the friction between soil grains under large shear strain.

The new method is in the developing phase. At present the suitable composition of the soil and its characteristics are in the process of being tested and studied. "Suitable" means that the curve of the relationship between the shear stress level and the number of loading cycles to liquefaction should lie as near as possible to the ideal curve (Fig. 2).

3. ANAlYSIS OF THE EFFECT OF THE SYSTEM

The effect and dynamic reaction of the building isolated with the new method has been analyzed. In this analysis the response of the structure in time was calculated both with and without isolator. For the description of soil-liquefaction process a model from Martin, Finn and Seed has been used /4/,/5/. A two-mass oscillator was used modelling the isolated structure. The superstructure was considered as linear-elastic with an eigenfrequency of 2Hz, and the isolator as a non-linear element. It was assumed that the isolator was filled with saturated natural fine sand having a relative density which can be achieved in reality.(This kind of sand is not the optimal material for the purpose.) With regard to the soil vibration signals, some recorded soil acceleration time histories of earthquakes in USA. and Europe and one earthquake wave artificialiy made for Europe have been used.

A part of the results of the analysis are shown in Table 1 and Fig. 3& 4. The response of the structural model with isolation is compared with that without isolation.

The results of the analysis show:
a) The isolator greatly reduces the energy input into the structural model. (Table 1 E_{dv} and E_{vg})
b) The maximum of response of the structure model is reduced considerably too.(Table 1 $\ddot{y}_{max}$)
c) The strong motion duration of the superstructure is shortened distinctly (Table 1 TTB).

Table 1: Response of the structural model

Stimulations	Systems	Response of the structural model					
		$\ddot{y}_{max}$	E_y	E_{dv}	E_{dg}	TTB	T_{VL}
Tolmezzo76 NS $\ddot{y}_{max}$=3.27 E_y=4.3,TTB=4.34	with Iso.	2.80	5.23	157	172	2.78	5.42
	without Iso.	11.8	282		9760	4.9	
TAFT52 N21E $\ddot{y}_{max}$=1.74 E_y=3.39,TTB=30.3	with Iso.	2.42	5.30	141	143	3.86	9.46
	without Iso.	5.05	75.4		2570	24.1	
ELCENTRO40 NS $\ddot{y}_{max}$=3.42 E_y=10.2,TTB=24.4	with Iso.	5.55	11.1	283	316	8.02	2.58
	without Iso.	10.1	196		6600	26.5	
artificial earthquake $\ddot{y}_{max}$=2.88 E_y=3.66,TTB=4.48	with Iso.	2.89	5.80	138	140	3.02	3.18
	without Iso.	4.57	29.6		1090	9.00	

Definition of the symbols:
$\ddot{y}_{max}$ –maximum acceleration (m/s²)
E_y –energy of acceleration in strong motion duration (m²/s³) /5/
E_{dv} –energy input into the structure before liquefaction (Nm)
E_{dg} –energy input into the structure in the whole duration (Nm)
TTB –strong motion duration (90% of E_{dg}) (s)
T_L –time of liquefaction (s)
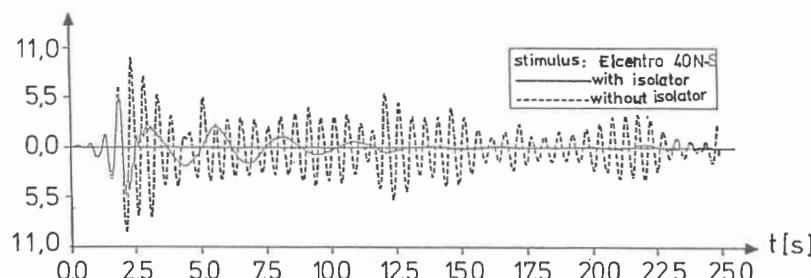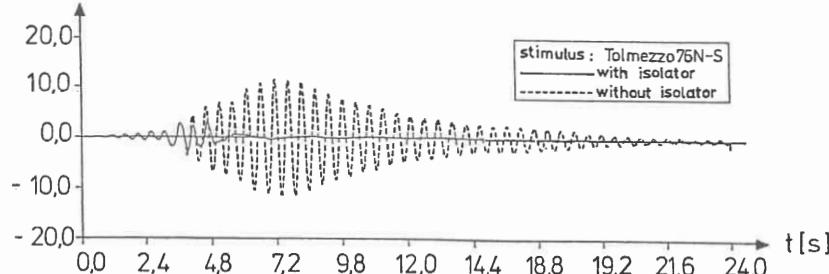
Fig. 3 & 4 Comparison of the responses between systems with and without isolator

After the experiments of the isolator-element have been finished, further analyses will be carried out so that the characteristics of the base-isolation system can be quantitatively described. In the analysis, a suitable model of soil composition according to the results of soil experiments will be used.

4.EXPERIMENTS

A test set-up for small-scale experiments has been made (Fig. 5). It consists of two parts: a structure model made of steel and an isolator model. In the isolator model, fine sand is filled in a rubber membrane. Through the valves and pipes leading into and the isolator model, the water volume within the membrane is controlled so that the sand is saturated and is kept in an undrained condition. During the test the structural model is vibrated horizontally by a small shaking table underneath, which produces a harmonic vibration.

These experiments have already been done. The Fig. 6 shows two of the time histories of acceleration responses of the same structural model recorded during the experiments. Fig. 6a shows the time history with isolator, and Fig. 6b without isolator. There is a significant difference between the two diagrams.
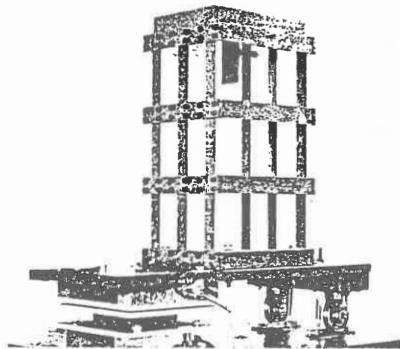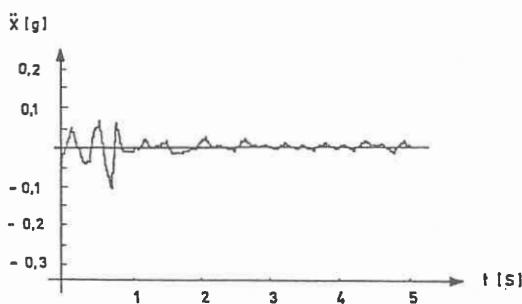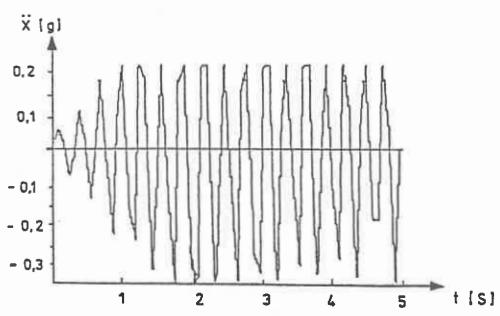
Fig. 5   Test set-up for the
small-scale experiments


a) with isolator

b) without isolator

Fig. 6 Top-acceleration of the structural model

The preparation for the middle-scale experiments on a shaking table in the laboratory is under way. The test equipment is made with the same principle of that of the small-scale one (Fig. 7). The experiments

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will be carried out in two stages. In the first stage, the construction of the isolator will be tested. The parameters of the soil mixture obtained from soil experiments will be verified. The influence of the membrane on the isolator will be measured. In the second stage, the whole isolation system will be tested in order to obtain quantitive information about the characteristics of the system. The calculation model of the system based on the theoretical analysis will be modified through the results of the test.
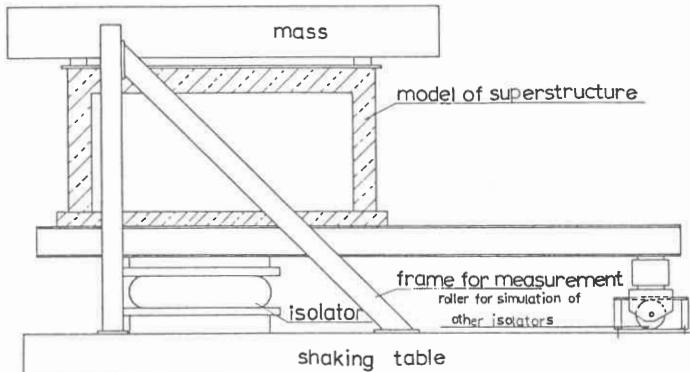

Fig. 7 Test set-up for the experiment on a shaking table

5. CONCLUSION

The new structure-subsoil isolation method is developed in view of practical usage. The analysis and tests previously done have proved the feasibility of this method. Furthermore, the material which is used comes directly from the nature, the construction of the isolation system is not complicated and maintenance is hardly needed. Therefore, it can be expected that this method will be an economical and practical approach towards structure isolation.

6. REFRENCES

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