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SEMI-ACTIVE CONTROL OF EARTHQUAKE INDUCED OSCILLATIONS OF STRUCTURES

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SUMMARY

Presented in this paper is a control system that operates on pure information (sensor and logic) and minimal energy (power) inputs, and thus it can be classified as semi-active. Moreover, an envelope control is characteristically for this method: The earthquake induced vibrational energy will be dissipated through the use of Tuned Mass Damper System (TMD) in conjunction with a ratch-release-mechanism intending of an optimum earthquake-response shooting. The new method of earthquake response control will be mechanical qualified by means of the SAMSON shaking table.

INTRODUCTION

Structural control has recently become an important topic of research in Civil Engineering (Ref. 1). It has an essential influence on the design of modern high rise buildings, especially with respect to their resistance to unsteady wind forces and strong earthquake motions. Passive vibration control techniques have been found more or less effective to alleviate structure response under hostile environments, such as strong earthquakes. In recent years different base isolation systems have been developed and practically applied for buildings (Ref. 2). To avoid the residual response the additional installation of damped vibration absorbers (TMD) at the top and/or lower levels of the structure may be useful. The authors have presented results of vibration control studies in such a way in the 8ECEE (Ref. 2).

Extensive experimental studies have been performed to create an appropriate 3-floor test structure describing the characteristics of the earthquake response with and without the new concept of semi-active (envelope) control. The method has been mechanical qualified by means of the SAMSON-shaking table. In conclusion and originated by the test results recommandations will be made from engineer point of view to improve the resistance of civil engineering structures against seismic attacks.

PASSIVE AND ACTIVE STRUCTURAL CONTROL

In order to limit structural dynamic response under environmental actions, such as earthquake, within acceptable ranges, two main control ways can be considered: the passive control, where the dissipation of vibrational energy is the aim and the active structural control, which generates counteracting forces by external means. Passive control systems have been used in practice to-date (Ref. 1).

Passive control It was found that the base isolation may be effective in reducing the structural response. Fig. 1 shows a typical acceleration response with fixed base and spring dashpot base isolation with 4 and 8 dashpots. The isolation efficiency essentially depends on the frequency ratio. Under certain circumstances it may be desirable to combine the use of base isolation and TMD systems for example. In such cases the base (isolation) tuning must be considered relating the TMD tuning. Moreover, the interdependence of the earthquake and the wind load versus fundamentaal period of structure are to be mentioned. Increasing natural period results decreasing earthquake load and increasing wind load, respectively.

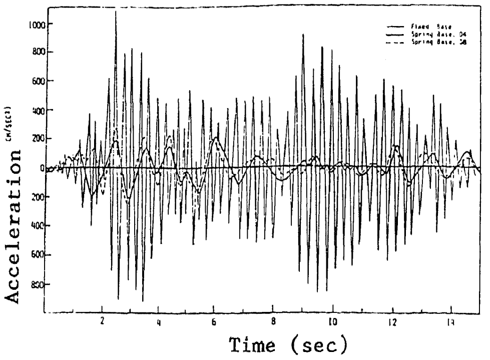


Fig. 1 Acceleration response fixed and spring-base

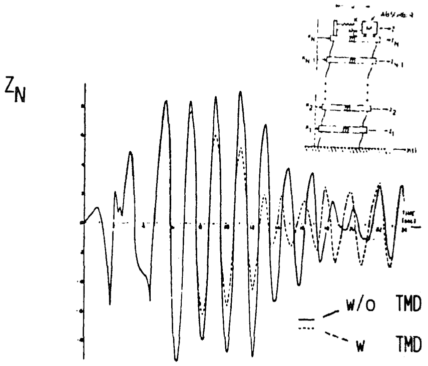


Fig. 2 Tip displacement with and without TMD

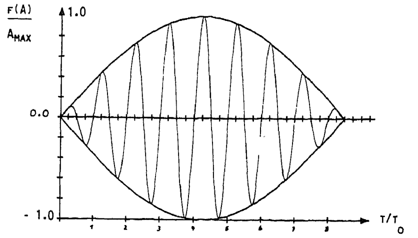
The tuned mass dampers have been found effective to reduce wind induced vibrations of civil engineering structures. However, investigations have shown (Ref. 4) that the TMD did not reduce effectively the maximum seismic response. Fig. 2 shows the displacement response of the MDOF structure with and without TMD. These findings have been contradicted by other authors (Ref. 1). The divergence of views is understandable since in case of white noise (random) ground acceleration the TMD is more effective than in the (realistic) transient excitation. Therefore, this paper deals with an improvement of the TMD system by means of the semi-active TMD with the aim of a transient counteraction.

Active control As discussed in (Refs. 3,5) much more experimental work needs to be done before the concept of structural control can be accepted by the structural engineering profession and the general public. Consequently the purpose of this paper is to investigate the effectiveness of the control technique by means of the SAMSON test facility.

SEMI-ACTIVE STRUCTURAL CONTROL

Various applications and techniques have been introduced including the use of active tendons to control the response of structures to unexpected excitations. Results of this investigations indicated (Ref. 6) that a significant amount of energy must be consumed in controlling the structure response. The proposed semi-active control technique avoids this disadvantage. As Fig. 2 shows, the reason for the uneffectiveness of the TMD to reduce seismic response is the inphase response of the structure and the TMD. To avoid this disadvantage the semi-active control makes possible the antiphase action by means of measurement the seismic transient response in time domain and starting the TMD decay at optimum moment.

Background As Fig. 2 shows, the transient seismic response in time domain is approximately sine-beat in the maximum range. Therefore, it seems to be possible to ensure an envelope semi-active control. The seismic response function may be as shown in Fig. 3. Important is the number of cycles in the beat. The vibration frequency is the natural frequency (e.g. base-tuned). The maximum of the response may be allowable or not and therefore a semi-active block diagram can be designed to realise the counteracting TMD. The shifting depends on the maximum structure response in the seismic region and also the expected number of vibration cycles.



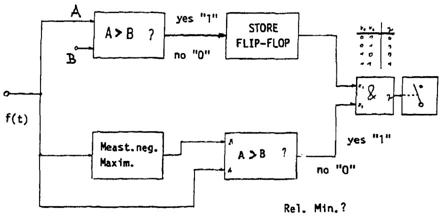
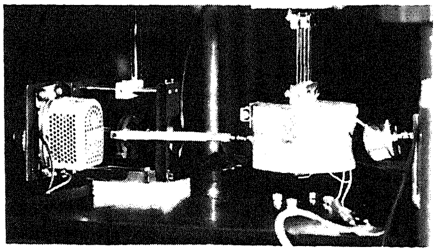


Fig. 3 Response-beat

Fig. 4 Block diagram of semi-active control

Experimental investigation The test specimen, a 3-floors steel-frame structure, was investigated on the SAMSON shaking table. The weights of the floors are 19, 18 and 18 kg from the bottom to the top. The weight of the 1170 mm high and 750 mm by 600 mm in plan dimension structure is 68 kg. The TMD mass is 6.5 kg and the damping viscously realized by the equipment as shown in Photo 1 and Fig. 5. The damping force P(t) is proportional $\dot{w}$ and consequently viscous if the shaft speed of the device is relative high in comparison to the oscillation-velocity $\dot{w}$. The roller-brake (3) and a light-weight brake-clamp with rubbing-elements (2) on the rotating shaft (1) is premised in this case. The TMD normally is in an excentric position to the normal due to electromagnetic force, released by electrical signal if the seismic induced motion of the test structure is maximum and in the best possible position to counteract that motion. The response will not be zero, because the maximum response is unknown at the time of prestressing TMD and the counteracting effect must be in an allowable measure.



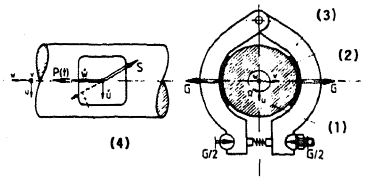


Photo 1 TMD with damping device and magnet

Fig. 5 Damping device

The vibration test facility (SAMSON Jülich) is a servo-hydraulic facility designed for the dynamic excitation of test specimens up to a weight of 25 t. A special feature of the vibration test facility is the possibility to control the motion of the shaking table in six axes (translation and rotation). The test facility is used in the design of components and for experimental verification of their safe functional capability under vibrational, sinusoidal and shock loads (e.g. earthquake). The vibration test facility - at present the largest installation of its kind in Western Europe - was installed on the site of Hochtemperatur-Reaktorbau GmbH with substantial sponsorship from the Northrhine-Westphalian Ministry of Economics and Technology. The main feature of the test facility is the shaking table, a welded steel structure measuring 5 m x 5 m x 1,2 m. It is designed for testing specimens weighing up to 25 t. The table is equipped with tapped holes for mounting the test specimens. Four hydraulic actuators, two by two operating in parallel, move the shaking table in both horizontal axes. Vertical excitation is ensured by a main actuator and four correcting actuators. This design permits independent motion of the shaking table in six degrees of freedom. The test facility is controlled by an analog system and a computer-based digital system, either of which can be used independently to control the facility. Motion of each of the six axes can be excited individually and simultaneously by the following types of excitation: time history (transients), sinusoidal tests (sine sweep, sine beat), and random tests. Photo 2 shows the test structure and Fig. 6 shows the SAMSON shaking table (Ref. 7).

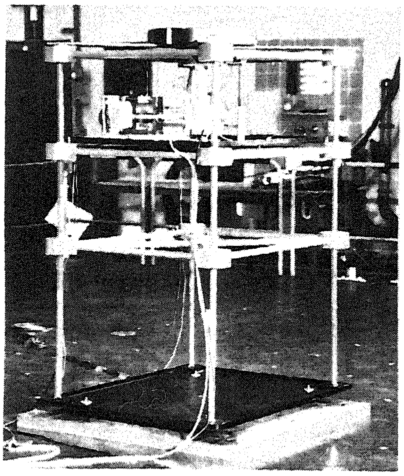


Photo 2 Test structure

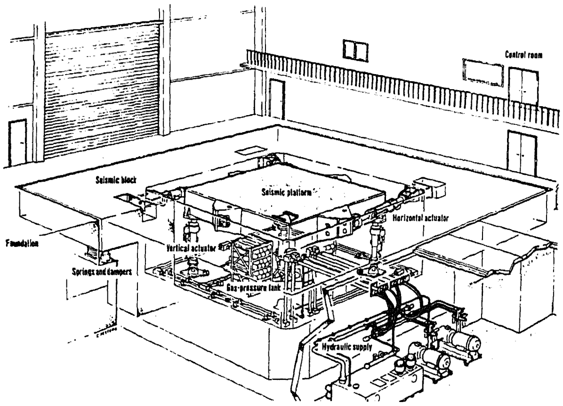


Fig. 6 SAMSON shaking table

In order to cover all tasks of study objectives a test program has been set up as briefly described in the following points: 1) Earthquake simulation (safety earthquake time-history) and structure response without control. The natural frequency of the structural fundamental mode is 2.36 Hz, verified by means of SAMSON sine sweep test. 2) Recording the TMD passive controlled structure. The natural frequency of the TMD (uncoupled) has been 2.3 Hz, i.e. optimum tuning with regard to optimum passive control of transient inputs. 3) Recording the semi-active controlled structural response, i.e. transient counter-attack. 4) Recording the structural response regarding the semi-active control turned the wrong way. 5) Recording the response due to excitation by the released TMD.

Test results   Fig. 7(a) compares the acceleration response at top level of the test-structure without and with the optimum TMD and additionally with semi-active control. It is clear that the TMD alter the response of the prototype building to the given earthquake record moderately. With the mass ratio 0.096 (with reference to the total mass of the test structure) a reduction results in peak response of 79 % (rest). The structural peak response without control has been 50 % gravity. The improvement by semi-active control is approximately 40 % refering TMD passive control. The response reduction effect is obviously and beyond that an improvement of the semi-active control by changing the set up time may be possible.

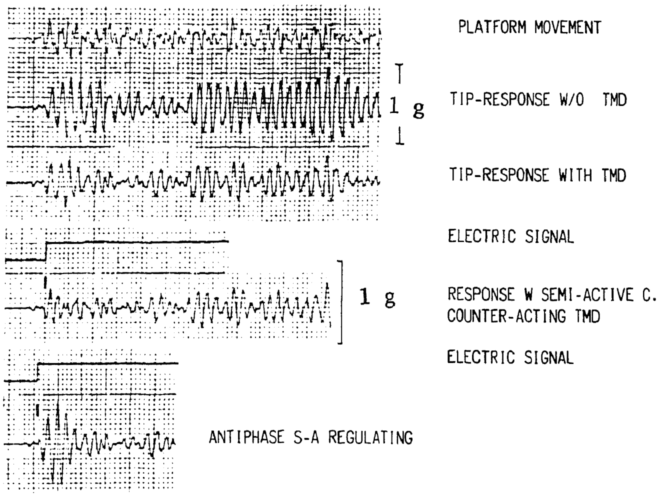


Fig. 7(a) Acceleration recordings

The acceleration response of the test structure top due to TMD decay shows Fig. 7(b). It is to be learned from this recording the transient counteraction.

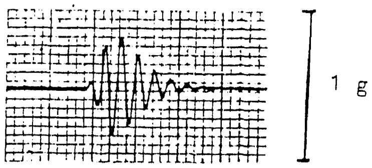


Fig. 7(b) Structure response due TMD decay

CONCLUDING REMARKS

In order to increase the control effect, installations of more than one TMD are possible. The different floors of the building can be carried out as TMDs with different tuning also with regard to the natural frequency of the higher structural modes of vibration. Basis of new aseismic design will be a structural optimization including elastic supported floors, optimum tuned and damped to reduce the response by means of a semi-active control technique as demonstrated in the way. Fig. 8 shows the drawing of a civil engineering structure with elastic supported floors.

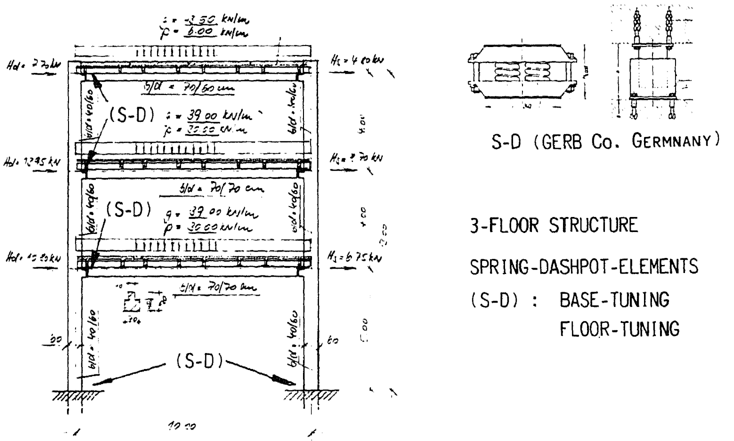


Fig. 8 Civil engineering structure with elastic supported floors (and base)

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