Seismic response reduction of a 12-storey reinforced concrete structure using semi-active resettable devices

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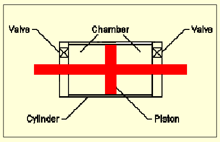
ABSTRACT: This paper presents an analytical investigation on the application of semi-active resettable devices to reduce the seismic response of a twelve-storey reinforced concrete structure.

1. INTRODUCTION

An experimentally validated resettable device is proposed to mitigate the seismic response of a twelve-storey structure. Fig. 1a shows a photograph of a 1/5th scale prototype of the device. The device has a two-chambered design that allows the use of each side of the device piston independently (Fig. 1b). Air is used as the working fluid of the device.

(a) Prototype device

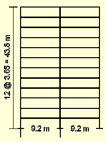


(b) Two-chambered design

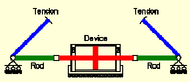
Figure 1. Semi-active resettable device.

2. IMPLEMENTATION OF THE CONTROL SYSTEM

The structure studied is shown schematically in Fig. 2a. It is considered to be a typical two-bay interior frame of a twelve-storey reinforced concrete building. The control system uses rigid rods attached to the two ends of the device piston (Fig. 2b). The rigid rods transfer the control forces to a tendon system. The tendon system consists of pre-stressed tendons that transfer the control forces to the structure at different floor levels.



(a) Building model

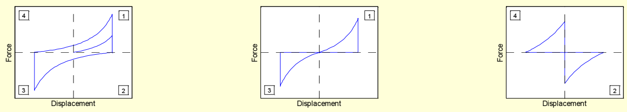


(b) System implementation

Figure 2. Implementation of the control system.

3. CONTROL LAWS, SYSTEMS AND EARTHQUAKE RECORD

The independent control of the device valves enables the re-shaping of the hysteretic behaviour by using different control laws. The control laws are based on the four quadrants defined by a sine-wave motion cycle. The laws are termed according to the quadrant of the force-displacement diagram in which the device provides resisting forces (Fig. 3).



(a) 1-2-3-4 control law **(b) 1-3 control law** **(c) 2-4 control law**

Figure 3. Control laws.

Fig. 4 shows the systems utilised to examine the effectiveness of resettable devices in reducing the seismic response. Nonlinear dynamic analyses are performed using the north-south component of the 1940 El Centro ground motion. The results are presented for comparison with the structure without devices referred to as the uncontrolled structure or system A.

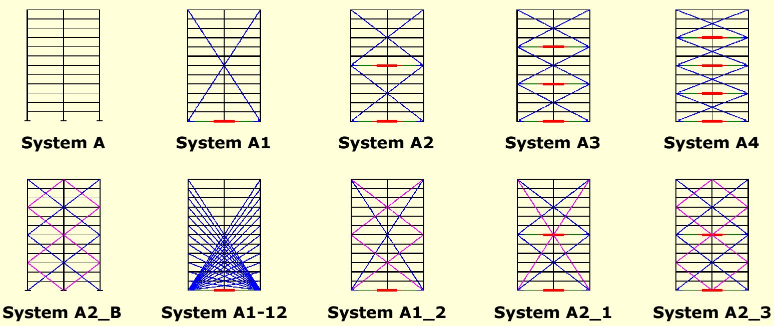
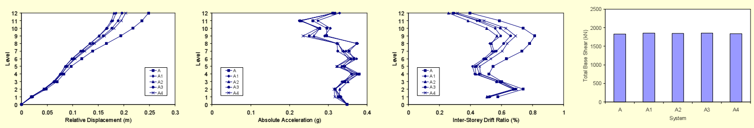


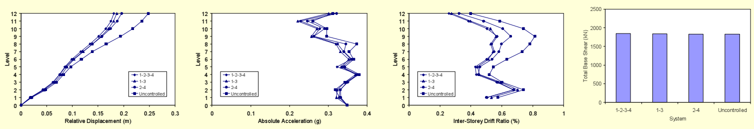
Figure 4. Systems under investigation.

4. EFFECT OF DEVICE DISTRIBUTION AND CONTROL LAW

Systems A1, A2, A3 and A4 are used to assess the effect of different device distributions on the seismic response of the building. The 1-2-3-4 control law is adopted to simulate the hysteretic behaviour of the device. Maximum response envelopes of the systems considered are shown in Fig. 5a. The system A2 is also chosen to analyse the performance of the different control laws under seismic excitation. Fig. 5b shows maximum response envelopes for the three control laws and the uncontrolled structure.



(a) Effect of the device distribution

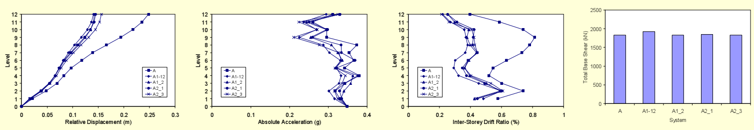


(b) Effect of the control law

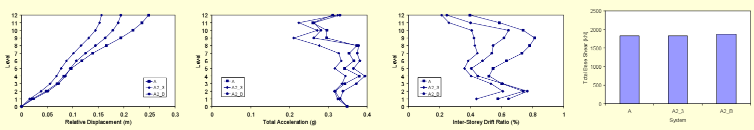
Figure 5. Maximum response envelopes.

5. EFFECT OF THE TENDON CONFIGURATION

Systems A1-12, A1_2, A2_1 and A2_3 are adopted to assess the effect of the tendon configuration on the seismic response of the twelve-storey building. The hysteretic behaviour of the resettable device follows the 1-2-3-4 control law. Fig. 6a shows maximum response envelopes for the tendon systems considered. The system A2_B is used to evaluate the contribution of the pre-stressed tendons and the bracing systems to the reduction of the earthquake response. Maximum response envelopes of the systems A, A2_3 and A2_B are compared in Fig. 6b.



(a) Effect of the tendon configuration



(b) Contribution to the seismic response

Figure 6. Maximum response envelopes.

6. CONCLUSIONS

- Increasing the number of resettable devices in the multi-storey structure did not reduce the earthquake response further. This effect is caused by actuator-actuator interaction and reflects the influence of higher modes on the seismic response of tall structures.
- The reduction of the seismic response achieved by the 1-2-3-4, 1-3 and 2-4 control laws was very similar. Moreover, the difference in response reduction delivered by the control laws was not significant. However, all control laws effectively reduced the seismic response of the structure.
- The use of pre-stressed tendons and bracings without resettable devices increased the floor accelerations and the total base shear of the structure. In contrast, the use of resettable devices combined with pre-stressed tendons and bracings reduced the floor displacements and inter-storey drifts, but without increasing the floor accelerations and the base shear demand significantly.