A STUDY ON PREDICTIVE CONTROL OF STRUCTURE WITH ENERGY CONSUMPTION UNDER SEVERE EARTHQUAKE

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1. Introduction[1)]

Structure control has already been recognized as an important methodology in designing new structures and retrofitting existing structures for earthquake and strong wind. The control of structural vibrations produced by earthquake or wind can be done by various means such as modifying stiffness, mass, damping, or shape, and by providing passive or active counter force. Up to now, research on active control systems has been mainly on the response control force type. These systems are relatively simple and easy to operate. However, as the structure becomes bigger and earthquakes become larger, much more energy is required to operate it.

The system is proposed as a seismic response control system used in this paper. It actively controls structural characteristics, such as stiffness of a building, to suppress the building's response. It consumes a relatively small amount of energy and maintains the safety of the building in moderate to severe earthquakes. The objective of this system is not only to minimize damage caused by potentially large destructive seismic forces and to protect human life, but also to assure structural safety and to maintain building functions and facilities. For this objective, the system controls the buildings response displacement to maintain the building under the safe state during severe earthquake.

2. Maximum Response Displacement

Current seismic design generally allows the structure to undergo inelastic deformation during severe earthquake. The amount of the design seismic force reduction depends on the deformation and energy dissipation capabilities of the structures. For this reason, it is important to estimate maximum response displacement during a real-time earthquake and its relation with the energy dissipation of the structure.

Based on the calculated maximum response displacement of elastic and inelastic single degree of freedom systems, which have the same initial period (same mass and stiffness), the energy theory and displacement theory are usually used to estimate the maximum response displacement and restoring force. For a short-period structure, the maximum dissipation energy stored in the elastic and inelastic systems has equivalent areas. For a long-period structure, the maximum inelastic displacement is almost equal to the maximum elastic displacement.

In this paper, an inelastic single degree of system was used, having bilinear hysteresis. The initial period of this system is 0.69s. Maximum response displacement in inelastic state was estimated at 7.5 cm. Here, one observed ground motion is expressed. This ground motion is record of Kobe. Acceleration time history is shown in Figure 1, the restoring force characteristic is shown in Figure 2.

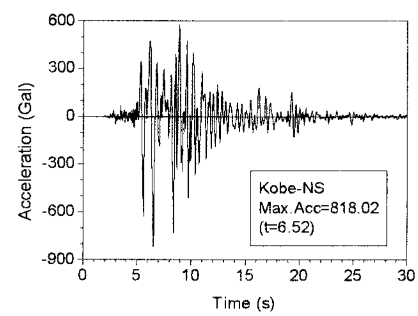

Figure 1 Observed earthquake motion (KOBE)

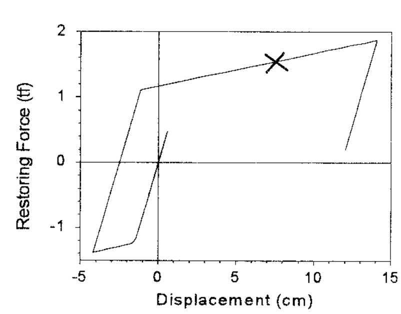

Figure 2. Restoring Force Characteristic (KOBE)

3. Stiffness Control Based on Energy Consumption

3.1 Energy Balance During Earthquake

The equation of motion of a single degree of system is given as

$$m\ddot{x} + c\dot{x} + F(x) = -m\ddot{z} \qquad (1)$$

From the equation (1), the energy equation is obtained [2)]

$$\int_{\bar{t}_1}^{\bar{t}_2} \ddot{\bar{x}}\dot{\bar{x}}d\bar{t} + 2h\int_{\bar{t}_1}^{\bar{t}_2} \dot{\bar{x}}^2 d\bar{t} + \int_{\bar{t}_1}^{\bar{t}_2} \bar{F}(\bar{x})\dot{\bar{x}}d\bar{t} = -\int_{\bar{t}_1}^{\bar{t}_2} \ddot{\bar{z}}\dot{\bar{x}}d\bar{t} \qquad (2)$$

the first term on the left-hand side of equation (2) is kinetic energy over the time interval; the second term is incremental energy dissipation by the damper; the third term is incremental strain energy absorption and hysteresis energy dissipation of the system; and the right-hand side of equation is called an incremental input earthquake energy.

From Figure 3 and Figure 4, input earthquake energy is considered to be relate with response displacement and maximum displacement always occurs just after maximum input earthquake energy inputted.

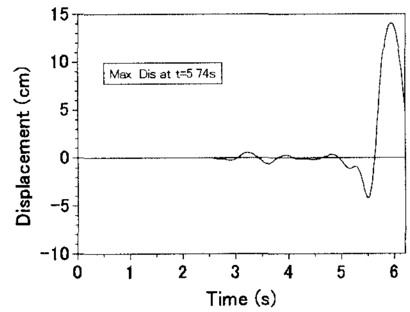

Figure 3. Displacement response

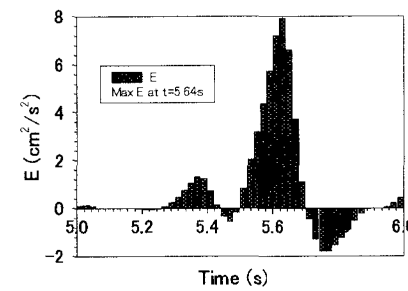

Figure 4. Incremental energy input per 0.02s

3.2 Method for Changing Building's Stiffness during Earthquakes

Input earthquake energy about 0.3s earlier than maximum displacement happened. During this time, compare the real-time dissipation energy with acceptable dissipation energy and predict destruction before it happens. The system increases stiffness by adds brace, then resistant force will be increased and response displacement will be controlled.

4. Composition of the Response Control System

All of procedure of this structural control was imagined as follows:

(1) The sensors placed on the ground measure the earthquake accelerations.

(2) The control computer analyze the real-time building's response and ground motion recorded, calculate the maximum input earthquake energy and estimate maximum response displacement, predict the destruction before it happens.

(3) The control computer sends command to the stiffness unit.

(4) The stiffness unit changes the building stiffness according to the computer command.

In the structure the emergency electric power source is placed. Even in case of a power failure, the system can still function with the uninterruptible power supply unit. This system consists of sensors, control computers and an uninterruptible power supply unit. And time of this procedure was assumed as: measure time + calculate time + control time.

5. Conclusion

In this study ten of earthquake records were used to approve of the method of predictive control structure with energy consumption and have gotten the satisfying result. Ten of earthquake records are applied to a single degree of system, now this structural control system only calculated by theoretical calculation. If this system is wanted to apply to real structures, experiment to using multi degree of system must be carried out.

References

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2) 西沢英和、金多潔：１自由度振動系のエネルギー応答について，日本建築学会構造系論文報告集，第 424 号，1991.