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Pseudo-dynamic testing method based on external displacement control

Dapeng Wang[a], Shizhu Tian[b]

Suzhou University of Science and Technology, 1701 BinheRoad Suzhou 215011, Jiangsu, China

[a]wangdapeng@mail.usts.edu.cn, [b]tianshizhu@mail.usts.edu.cn

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Abstract: In order to accelerate the velocity and improve the accuracy of the pseudo-dynamic testing, the external displacement control method is put forward based on the hardware control. The internal displacement sensor of the actuator is invalid on control and substituted by the LVDT displacement sensor connected with the specimen. The process of the feedback displacement and command error compensation is quickly implemented by the internal closed-loop control of the actuator. Compared with the iteratively approximate load control, this method not only makes the testing velocity fast, but also enables the error between command and feedback to be "zero". The fast pseudo-dynamic testing about a cantilever beam is carried out by applying appropriate PID parameters of the actuator. The testing result shows that although this method has rather high requirements in the control system and electro-hydraulic servo load device, and the risk to some extent, the fast response of the actuator can be firmed by applying appropriate PID control parameters. This method provides a fast testing technology for velocity-dependent structures or specimens.

Introduction

The pseudo-dynamic testing method is an advanced seismic testing approach through combining physical experiment and numerical simulation. It can change the real-time dynamic testing into low velocity loading testing by means of calculating the effects of the inertial force and the damping force, which makes it possible to carry out the structrual testing with large-scale even full-scale models. Especially, the sub-structural testing technology enables to carry out large-scale model testing only on the key parts or complicated parts of the whole structure, while the rest of the structure can be numerically simulated. This will decrease the testing cost to large extend. The seismic testing has been applied widely in seismic research of civil engineering since the first pseudo-dynamic testing of the world was implemented by Takanashi[1] in Japan. With the development of the theory, algorithm, technology and device, the recent pseudo-dynamic testing method has largely different with the initial. The shortcoming of the method is that the lower loading velocity will have some effect on the testing results of some structures with relatively high damping material, especially for the passive energy dissipation. Several approaches of fast, continous and real-time pseudo-dynamic testing method and technology have been made to overcome the shortcoming[2~6]. Among these approaches, most are based on the predicted and modified algorithms of software technology to implement the fast and continous loading of the actuators. A kind of external displacement control based on the hardware of electrohydraulic servo testing device is addressed to implement the fast testing.

Loading Control Method

Ramp Load Control. During the process of pseudo-dynamic testing, the target command of the actuators will be sent out by the ramp mode beginning at the point that the previous testing step stops in oder to aviod the excess stroke action of the actuator, which will last so long time. There is still needed to wait for some instance to implement the acquisition of the specimen feedback in order to keep the actuator in the stable state. Take displacement control as an example, the ramp loading flow can be shown in Fig.1. So is the force control.

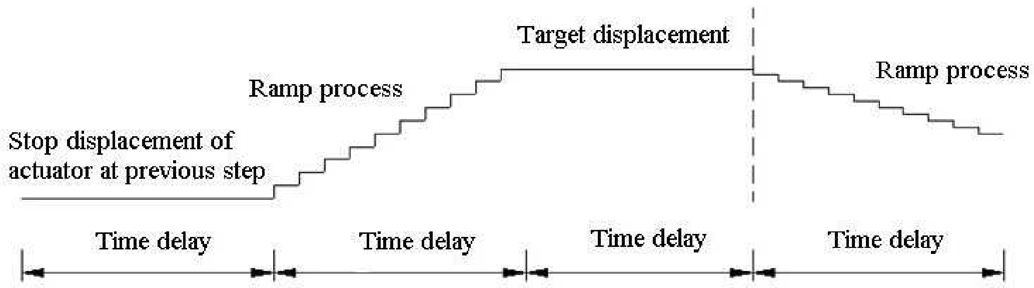


Fig.1 Ramp load control method

In fact, the loading control method sometimes will last so long time that makes the time of one testing step more than 100 times of the actual ground motion interval. This loading process usually lasting 3 to 6 hours has the obvious shortcomings as following:

(1) The phenomenon of force relaxation of the specimen will occour during the sustaining of the actuator command. The error resulted from the phenomenon will be brought in the numerical simulation program, which will have some effect on the testing precision.

(2) Although the continous command signal enable to make the actuator move continously, the static friction occurred during the process of actuator from stopping to moving will result in the slight shaking of loading process.

(3) At the moment of the command from ramp to sustaining, the actuator with incorrect tuning gain parameter will undertake the excess stroke action because of the discontinuous loading velocity.

Iteratively Approximate Control. During the loading process of pseudo-dynamic testing, the displacement of actuator sensor is not equal to that of the specimen because of the gap between the electrohydraulic servo actuator and the specimen and the counterforce wall, the movement between the specimen and the support, and the tiny elastic deflection. In order to simulate the adequate earthquake action result in numerical program, it is important to implement and obtain the correct displacement feedback of the specimen. Usually, as shown in Fig.2, an iteratively approximate control method will be used to compensate the error between the actuator command d_{i+1} and the feedback displacement $d_{i+1}'$of specimen.

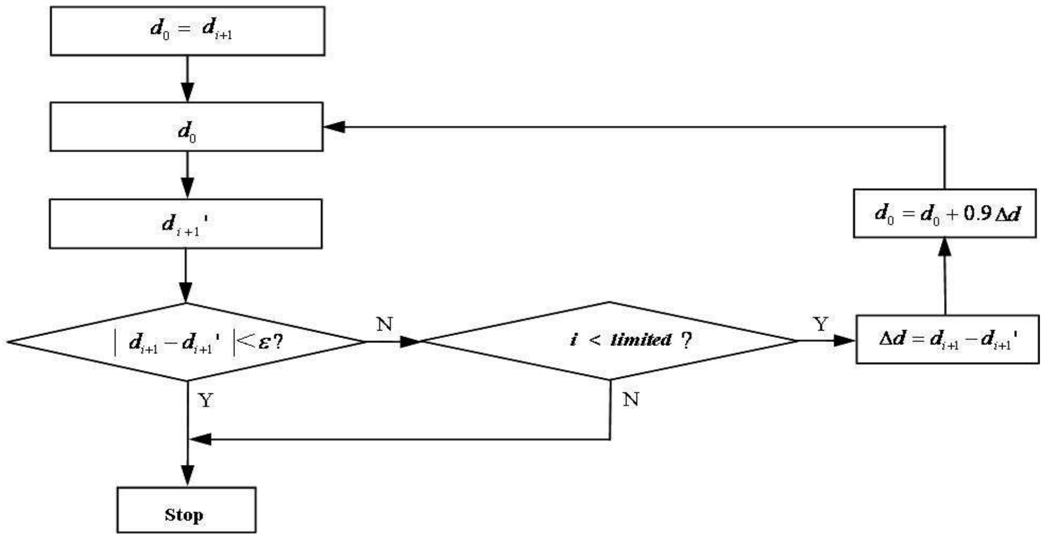


Fig.2 Flow chart of iteratively approximate control

The process will be implemented after several iteratively approximate. There are some key points as following:

(1) There needs an acceptable limitation error ε to stop the iterative process between the feedback displacement of specimen and the target displacement. It is obvious that the limitation error will affect the testing velocity. The large limitation error will result in bad precision while accelerating the testing process. The small limitation error enable to improve the precision and affect the loading convergence.

(2) There also needs an iterative limitation number in order to avoid the actuator moving iteratively but not stopping at one step. The limiation number should also be suitable. The small limitation number can accelerate the testing velocity but bring in large testing error. The large limitation number will slow down the testing velocity.

(3) During the compensation process, the compensation increment every time will be multiplied a coefficient 0.9 (or a number less than 1) in onder to keep the actuator pull or push at the same direction.

External Control Mode

External Command Control. Generally, a sort of electro-hydraulic servo load system is used as the testing equipment in order to implement the function of continuous load to the testing model, which consists of the actuator system as load facility, the digital controller and a PC with control software working together as a tightly integrated system. The PC and the controller are usually linked by Ethernet connection, providing fast, reliable communications and data transfer. The actuator system and the controller are connected by special circuitry. Closed-loop control to the actuator is completely managed by the digital controller. During the process of a testing, control software sends the target command to the actuator and receives the feedback from the actuator via the input/output (I/O) channel of controller box, that is, if the input/output (I/O) channel of controller box is dominated, the control to the actuator is implemented.

The controller box of most control system often provides the hardware interface of I/O channel that enable users to connect other hardware devices. Therefore, the control to the I/O channel of the controller and the actuator can be realized by controlling these hardware devices. Although this approach needs an additional computer to program to control these hardware devices, it provides easily operational hardware connection and makes it flexible and convenient for users to develop testing system or function by using familiar program language. Since the control to the actuator is achieved through external command signal from hardware devices, the process of programming can avoid complex low-layer technology of control software. Because the approach only has relation with hardware device additional connected, it is also suitable for any testing control system. In addition, if the hardware condition is permitted, several control system can be integrated into one whole body to carry out many substructure testing in local laboratory.

Generally, the Analog/Digital (A/D) and Digital/Analog (D/A) acquisition board are selected as the additional hardware to connect with the I/O channel of the controller. The control to actuator is achieved by programming to control the acquisition boards in industry computer. As shown in Fig.3, it is a familiar hardware connection. During the testing, the voltage signal of the feedback displacement is received from LVDT (Linear Variable Differential Transformer) sensor connected with the specimen and collected into A/D acquisition board. The voltage signal of the feedback force is received from load cell of the actuator and collected into the Analog Input (AI) channel of the controller box, and then output via the Analog Output (AO) channel and collected into A/D acquisition board. The voltage signal of the target displacement is sent out into the AI channel of the controller box via D/A acquisition board, and then output into the actuator via the AO channel to move the actuator.

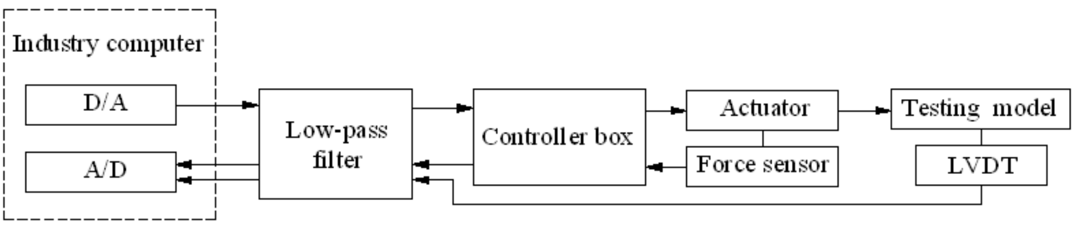


Fig.3 Flow chart of external command control

External Displacement Control. Originated but different from the external command control, the external displacement control uses the LVDT connected on the specimen instead of the inner displacement sensor of actuator, which make the compensation between actuator command and specimen feedback implment by the inner close-loop control of actuator, as shown in Fig.4. Differet with the external command control, the external displacement control will be more fast and adequate because once the target command is sent out, it will be implemented on the specimen accurately. There is still some questions that should be considered as following:

(1) Although the signal of external displacement control is also sent out as ramp mode, it is more fast and precise because the command sustaining process and the iteratively approximate compensation process are not exsited.

(2) There is still tasks using this method because the LVDT sensor connected on the specimen participates the control process. Except for better precision, the LVDT sensor should have high reliable connection with the specimen.

(3) The correct PID (Proportion Integration Differentiation) parameters should be configured to enable the actuator to move quickly.

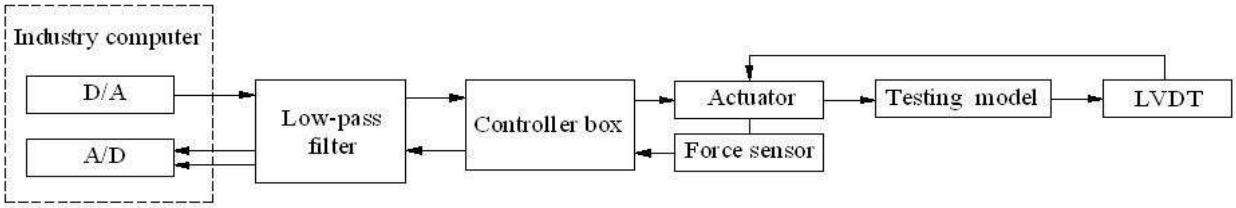


Fig.4 Schematic diagram of testing system with external displacement control

Pseudo-dynamic Testing about Catilever Steel Beam

Testing Specimen and Testing Equipment. The testing model was a cantilever steel beam that can be simplified as a SDOF specimen. As shown in Fig.5, the testing model was fixed on the foundation. The electro-hydraulic servo actuator was horizontally placed to load force between the top of the steel beam and the strong reaction wall. The top horizontal displacement of the specimen was measured by an LVDT with the range of -50 to +50mm. The restoring force was measured by the load cell built in the -250 to +250kN capacity actuator.

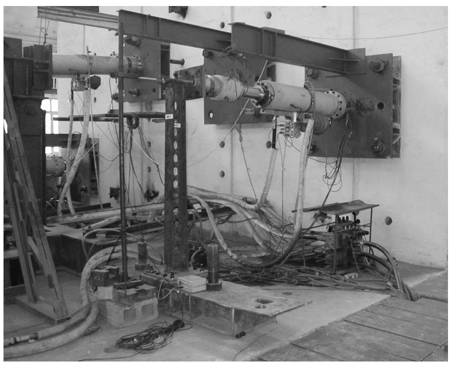
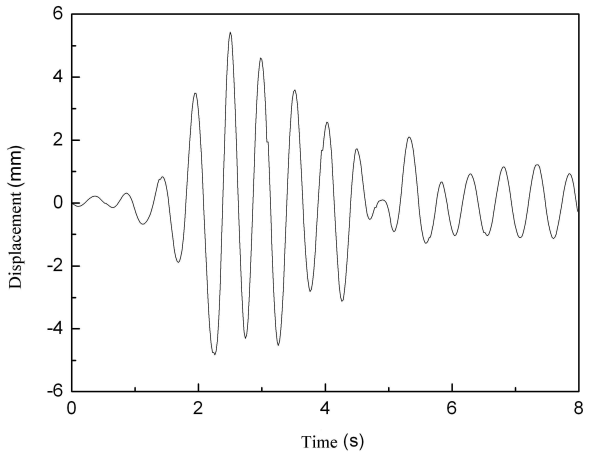


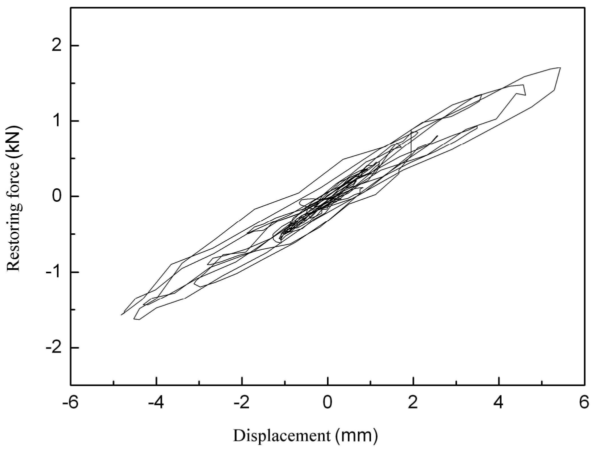
Fig.5 Testing specimen and testing equipment

Testing Parameters. The stiffness was 350kN/m, the mass was 2.21×10^3kg, and the damping ratio was 1%. The earthquake ground motion acceleration record is the EL-Centro (NS, 1940) with the peak acceleration of 3417mm/s2 and the interval of 0.02s. During the testing, the first 400 steps of the earthquake wave were conducted with the peak acceleration reduced to 350mm/s^2.

Testing Results. The time history curve of displacement and hysteretic curve are shown in Fig.6. The testing is carried out in the state of high velocity. The time cost in each step less than 10 times of the actual ground motion interval. It is a pity to carry out more fast testing because of the performance limitation of the acturator. The testing successfully validated the usability of the developed testing method.



(a) Time history curve of displacement



(b) Hysteretic curve

Fig.6 Testing results

Conclusions

(1) As a control approach based on the hardware, the external displacement control can overcome the shortcoming of classical ramp control and iteratively approximate loading, which can be used to carry out some seismic testing research on structures or specimens dependent with velocity or acceleration.

(2) The LVDT sensor connected on the specimen should have high precision and reliable in order to ensure the testing accuracy and safety.

(3) The PID parameters should be adjusted iteratively for the actuators with different performance.

Acknowledgements

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