Newsletter on the Latest Technologies Developed by RTRI

Railway Technology Avalanche

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ARTICLES

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Developing New Technologies for Solving Various Railway Issues

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I consider it meaningful to review at this moment the major issues Japan's railway business is now faced with and the development of new technologies that are needed to solve them. Those issues concern the ongoing demographic change, global environment and railway safety. Specifically, the demographic change means the declining birthrate and the aging society, which translates into fewer railway users. If the present trend continues, it should become increasingly difficult for the railway business to secure sufficient employees and maintain the level of railway technology. Concerning the global environment, reducing CO_2 emissions is a major challenge. As for railway safety, it is important to provide against big earthquakes which are anticipated in the near future in certain urban areas and areas along the Shinkansen lines and to prevent train accidents. (For example, in a resent case, a train running at abnormally high speeds derailed and overturned, taking a heavy toll.)

Railway operators are striving to enhance the efficiency of operations, introduce energy-efficient vehicles, improve signaling systems and develop new monitoring systems for preventive maintenance.

In order to solve the issues mentioned above, it is necessary to develop new low-cost, high-performance technologies based on entirely new concepts, aside from existing technologies. To carry out R&D on safety problems to prevent recurrence of railway accidents, RTRI has revised its R&D program. For example, RTRI has tackled development of a low-cost speed-check ATS system, a new train control method utilizing general-purpose radio and a new method for assessing railway risks. In addition, as measures to save energy, we are developing a new synchronous motor for vehicle that helps reduce the AC loss, a new transformer for the Shinkansen system utilizing superconducting coils and basic technology for fuel cell-driven cars. Research on reduction of the weight and running resistance of vehicles contributes to savings of energy.

In addition, the problem of maintenance of railway facilities cannot be neglected. Many of the railway tunnels, bridges, etc. have become noticeably superannuated. There are cases where the superannuation is accelerated as a result of an unexpectedly rapid increase in traffic volume. In order to renew superannuated facilities or carry out works to prolong their life in a planned manner in the future, it is necessary to come up with economical diagnostic methods and work methods.

From the standpoint of activating railways, positive R&D is also called for. I consider it the railway people's duty to increase the use of railways as an excellent means of mass transportation, decrease the use of automobiles and airplanes, expand the share of railways and thereby contribute to the improvement of the global environment. The experimental TGV marked the speed record of 574.8 km/h in April 2007. In that respect, I pay my respect to the French railway engineers. The achievement is very significant not only to French railways but also to railways of the whole world. The fact that the distributed drive system used on Shinkansen was adopted on the experimental TGV also impresses us.

It is not too much to say that the future of railways rests on R&D having clearly defined goals. Therefore, RTRI continues attaching importance to the international cooperation with railway operators, university researchers and makers of the world.

Development of a Testing Machine with a Large Tunnel Lining Model

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1. Introduction

In evaluating the soundness of a tunnel and designing ground reinforcement work, it is extremely important to understand the mechanical behavior of the tunnel lining. However, the deformation of tunnel linings is difficult to understand since it depends largely on the action of the ground surrounding the tunnel, the occurrence of cracking in the lining, and other factors.

So far, the Railway Technical Research Institute (RTRI) has studied, with some tangible results, the influences of various loading patterns and structural defects, using a testing machine comprising 1/30 scale lining models with a standard Shinkansen tunnel cross section in experiments focused on the mechanical behavior of tunnel lining. However, since it was not always possible to quantitatively evaluate the mechanical behavior of the lining using a 1/30 scale model, the RTRI has developed a new testing machine with a larger lining model—a 1/5 scale model with a standard Shinkansen tunnel cross section.

2. Testing Machine

The scale of the testing machine is 1/5 of the standard cross section of a Shinkansen tunnel (Photo 1, Fig. 1). The testing machine is provided with a total of 27 loading points—nine loading points in the tunnel circumferential direction in each of three rows in the tunnel axial direction. Servo-actuators are used to apply loads. The system configuration and specifications of the apparatus are shown below.

(1) Loading equipment
- Hydraulic jacks for applying loads (with displacement and load meters)
  - Maximum working pressure:
    - Pressing force 500 kN (5.6 MPa)
  - Maximum stroke: 250 mm
  - Loading plate:
    - 300 mm sq. (lining-side curvature R = 1,075 mm)
- Hydraulic cylinders for applying reaction force (with ground springs)
  - Cylinder inside diameter: 125 mm
  - Maximum stroke: 200 mm
  - Rated pressure:
    - Normal 16.3 MPa (equivalent to 200 kN)
  - Conical spring:
    - OD 200 mm x ID 102 mm x thickness 12 mm
    - 20 pieces/point; spring constant 30 kN/cm

  After a hydraulic cylinder load is set, the load is retained by a stop valve. Any deformation load after that is received by the conical spring deformation.
- Reaction force frame
  - Dimensions:
    - 5,600 mm W x 1,200 mm D x 3,860 mm H
  - Mass:
    - Approx. 30 kN (main frame only)

(2) Hydraulic equipment
- Air-cooled hydraulic unit (rated pressure: normal 20.5 MPa)

(3) Lining model
- 1/5 scale model (R = 925 mm) of standard cross section of a Shinkansen tunnel
  - Dimensions:
    - Width 1,850 mm (within SL) x height 1,175 mm (inside height) x wall thickness 150 mm x depth 300 to 1,200 mm

3. Example of Load Test

An example of a one-point vertical load test is given below. A test load was applied stepwise, with displacement control for 0.5 mm push of the loading plate in each step. After a displacement was given, the test piece was left for one minute. Then the measurement data was input and the test piece was examined for cracks. The lining material was plain concrete (fck = 21 MPa), and the model depth was 300 mm—the width of the row of loading plates. The load-displacement curve obtained is shown in Fig. 2 and the conditions of cracking and deformation are shown in Photo 2 and Fig. 3.

In this particular example, the lining that was subjected to the test load showed elastic behavior at first. Even after it cracked and flexural compressive fracturing occurred, the load continued increasing, although the rate of increase declined. The lining remained in a state of ductile fracture for some time even after the peak load was reached, and then the load began decreasing, resulting in the ultimate state of the lining.

4. Conclusion

In the future, the RTRI intends to use the new testing machine to establish methods for evaluation of mechanical soundness and for reinforcement of tunnel linings.

Photo 1 Appearance of newly developed testing machine

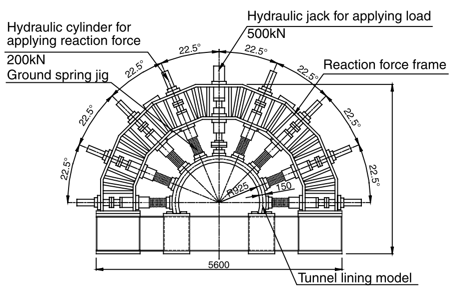

Fig. 1 Outline of testing machine

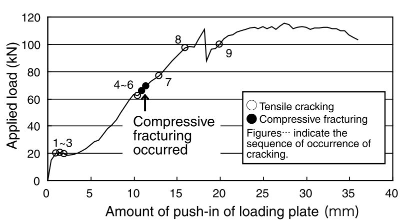

Fig. 2 Load-displacement curve

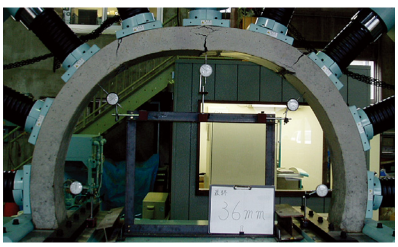

Photo 2 State of cracking and deformation (at final push-in)

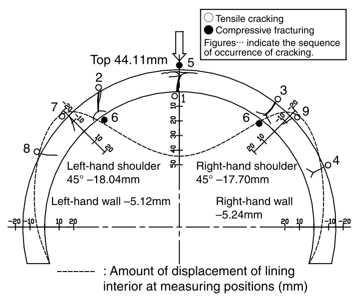

Fig. 3 State of cracking and deformation (at final push-in)

Development of Superconducting Magnetic Bearings

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Electric power is a type of energy that is absolutely indispensable to our daily lifestyles, and the effects of its consumption patterns on the global environment are significant. In recent years, hopes have become increasingly pinned on the equalization of electric power loads using electric power storage technology as a means of alleviating global warming. Even in the railway sector, there is a high likelihood that it will be possible to apply electric power storage technology for such purposes as ensuring that the regenerative power of electric trains is effectively utilized and improving the reliability of electric power supply in information systems.

It is against this backdrop that our research laboratory has been working on a research and development project for magnetic bearings that apply superconductivity technology and that will be used as the support bearings of the flywheels used for storing electric power. On the one hand, flywheels have a high energy density and are extremely useful for running systems characterized by start/stop operation and load responsiveness, but on the other hand there are problems with the service life and economic aspects of their systems. Our research project has the objective of resolving problems concerning the maintenance of mechanical parts and offsetting the reductions in operating efficiency due to such factors as the friction loss in the bearing parts, and it aims to attain these objectives by supporting the flywheels using superconducting magnetic bearings.

Superconducting magnetic bearings are characterized by the fact that they combine superconducting coils with high-temperature bulk superconductors. Configuring the magnetic bearings using superconductors has the effect of eliminating the constraints both on the limits of the magnetic fields applied in conventional magnetic bearings featuring a combination of conventional permanent magnets and bulk superconductors and on the limits of the magnetization attained using magnetic bearings that utilize the power of attraction of ferromagnetic material and the superconducting coils, enabling the load capacity of the bearings to be increased.

Figure 1 shows an illustration of the superconducting magnetic bearing that has been created as a prototype. Part of the rotating shaft configures a liquid nitrogen Dewar vessel containing a 60 mm diameter bulk superconductor that is cooled by the liquid nitrogen. This rotatable Dewar vessel is positioned at the through hole of the superconducting coil to configure a magnetic bearing.

When a bulk superconductor is used in conditions where it is cooled by liquid nitrogen, the applied magnetic field is limited to less than 2T by the critical current of the bulk superconductor at 77 K. For this reason, a superconducting coil that can create a cusped magnetic field through the heteropolar excitation of two coils was developed as the superconducting coil to be positioned on the fixed side of the bearing. By creating a cusped magnetic field, the magnetic flux in the axial direction is canceled out to zero in the axial (vertical) center of the two coils, and the magnetic field gradient in the axial direction reaches its greatest proportion in the place where it is slightly moved in the axial direction from this point. When a bulk superconductor is positioned in this place, a high levitation force that has an applied magnetic field of less than 2T and that is proportional to the magnetic field gradient is generated. In this way, it is possible to support a bearing load commensurate with the levitation force.

Figure 2 shows an example of the results obtained from a static load test on superconducting magnetic bearings. In this experiment, a levitation force of 8 kN was generated. Future plans call for tests involving flywheel rotating bodies weighing 500 kg to be supported by superconducting magnetic bearings and to be rotated at high speeds in order to ascertain the bearing characteristics.

Implementation of part of this research project was made possible by a state subsidy from the Ministry of Land, Infrastructure and Transport.

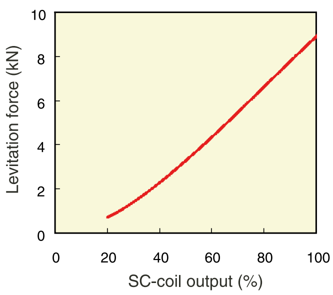

Fig. 2 Results obtained from a static load test

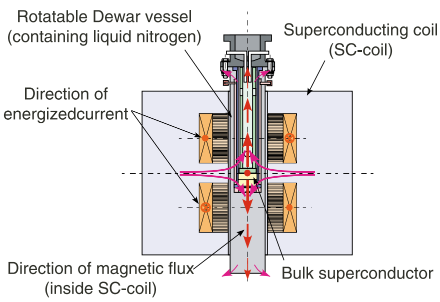

Fig. 1 Structure of a superconducting magnetic bearing

Apparatus for measuring the electromagnetic force generated by a bulk superconductor positioned inside a superconducting coil

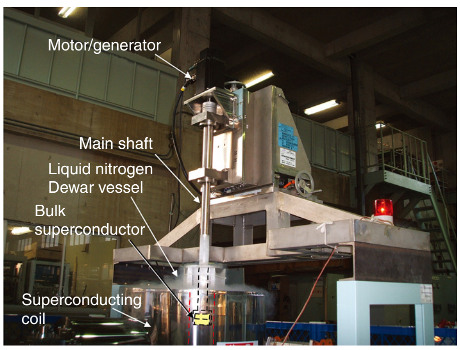

Fig. 3 Apparatus used for the experiment

Reduction of Carbody Vertical Bending Vibration by Controlling the Primary Suspension Damping Force

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With the increase in speed and the decrease in weight of railway vehicles, the carbody vertical elastic vibration (particularly the primary bending vibration) has become noticeable. This vibration can lead to a deterioration in the vehicle vertical ride quality. Therefore, various measures to reduce this vibration have been proposed. In any of the vibration-reducing methods that have been proposed so far, the force required to restrain the vibration is applied directly to the carbody by a suitable means, with or without control of the force. The salient characteristic of the method proposed in the present R&D is that it controls the damping force of the primary suspension system to restrain the vibration of the trucks that are the major cause of carbody vibration, thereby reducing the vibration of the carbody. By controlling the damping force of the air spring (secondary suspension system) as well as that of the primary suspension system, it is also possible to reduce the vibration in rigid body mode, and further improve the ride quality.

System configuration

As shown in Fig. 1, the system is composed of acceleration sensors, variable damping axle dampers and a controller installed on the truck frame. Where necessary, acceleration sensors are also installed on the carbody. Based on data obtained by the acceleration sensors, the controller calculates the optimum damping force for reducing the primary bending vibration of the carbody and controls the damping force of the variable damping axle damper.
The variable damping axle damper (Fig. 2) has such a high response that it is capable of controlling damping forces up to approximately 10 Hz. The decline in damping force when the damper displacement amplitude is extremely small is kept to a minimum. Since the space required for installation and the maximum damping force of the variable damping axle damper are the same as those of the passive axle damper currently in use, the two types of dampers are interchangeable even in terms of the strength required for the damper attachment bracket, etc. When the air spring damping force is also to be controlled, an air suspension with a built-in variable damping valve (Fig. 3) and sensors for measuring air spring displacement are used.

Results of excitation testing at rolling stock test plant

The system was mounted on a test vehicle modeled on an actual Shinkansen car and subjected to an excitation test simulating the actual running conditions at the RTRI rolling stock test plant. Fig. 4 shows the power spectral density (PSD) of vertical vibration acceleration at the floor of the carbody center. Peak PSD caused by the carbody primary bending mode was observed in the neighborhood of 8.5 Hz. It was found that the vibration could be reduced to approximately 15% by controlling the axle dampers. In addition, with the aim of confirming the improvement in ride quality by the reduction of vibration, the test car's ride quality level (L_T), which is used as an indicator of ride quality of railway vehicles in Japan, was calculated. The calculation results are also shown in Fig. 4. It was confirmed that the control of the damping force by the system was effective in improving the ride quality—reducing the L_T value by about 4 dB.
When the air suspension damping force was controlled at the same time, the vibration in rigid body mode around 1 Hz decreased to about one-half in terms of PSD peak value, and the L_T value improved by about 4.5 dB.

Future plans

The system was mounted on a Shinkansen test car, which was subjected to a running test. As a result, it was confirmed that the system effectively reduced the carbody vertical bending vibration and reduced the L_T value by 3 dB or more. In the future, we have plans to press ahead with activities to put the system into practical use— including cutting the cost of the variable damping axle damper, mass-producing the system, and carrying out long-term durability tests with prototypes.

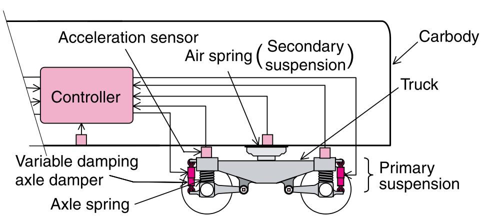

Fig. 1 System configuration

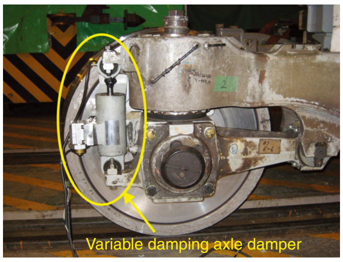

Fig. 2 Installation of variable damping axle damper

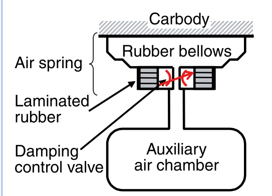

Fig. 3 Air suspension with variable damping valve

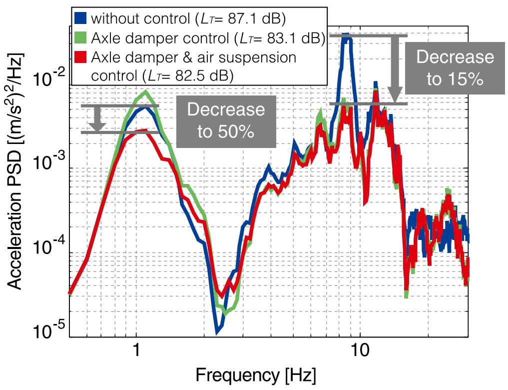

Fig. 4 Acceleration PSD at the floor of carbody center

Running Test of Experimental Fuel Cell-Driven Car

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With the aim of saving energy, reducing the environmental and conserving fossil oil and other depletable fuel resources, Railway Technical Research Institute is developing railway cars driven by fuel cells. Through a series of driving tests using actual railway car bogies equipped with a 30 kW class fuel cell system, we have already confirmed that fuel cells are viable as a power source for driving railway cars. Recently, we developed a 100 kW class fuel cell system that can be mounted on a car (Fig. 1), together with a high pressure hydrogen tank system, etc. The fuel cell system was mounted on a test car (Fig. 2), which was made to be capable of running for itself. This car was provided with a current collector, which was intended for use primarily as a static inverter (SIV) for auxiliary use. As long as the air pressure for braking is sufficient, the car is capable of running with the current collector folded down. This test car does not have a way to store energy, and therefore cannot absorb the power regenerated during braking or provide extra power during acceleration. A test track (about 650 m) laid in the yard was used to carry out a running test of the test car. It was the first running test of an actual railway car driven by a fuel cell system: all the tests of fuel cell-driven cars that had been carried out to that point were static ones. In the running test, it was also necessary to confirm whether the fuel cell system would be adaptable to an environment under which it would be subject to the vibration, acceleration, etc. of the test car in operation. Fig. 3 shows the results of the running test of the test car driven by the fuel cell system. It was confirmed that the fuel cell system was unaffected by the vibration and acceleration caused by the running of the car and that it could operate stably up to a car speed of about 40 km/h and a fuel cell output of about 90 kW. In order to confirm the running performance at higher car speeds, a simulation running test on a test platform was carried out. The test results are shown in Fig. 4. The maximum stable running speed was about 105 km/h. At a speed of about 40 km/h, the output began to decrease. This was due to an insufficient supply voltage. In another test carried out to confirm maximum output, the maximum output was 115 kW, indicating that even under load fluctuations a maximum output close to the rated output (120 kW) could be secured. Based on those test results, the fuel consumption and efficiency were evaluated. The evaluation results are shown in Table 1. It can be seen that fuel consumption varies markedly according to the mode of operation. The efficiency was confirmed to be as high as about 50%. In the future, we plan to develop an energy accumulation system and establish fuel cell hybrid technology. Part of the present R&D was carried out with a subsidy granted by the Ministry of Land, Infrastructure and Transport.

Fig. 2 Experimental fuel cell-driven car

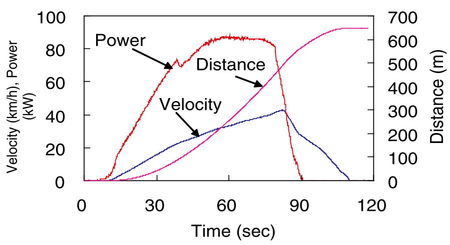

Fig. 3 Results of running test in yard

Fig. 1 100 kW class fuel cell system

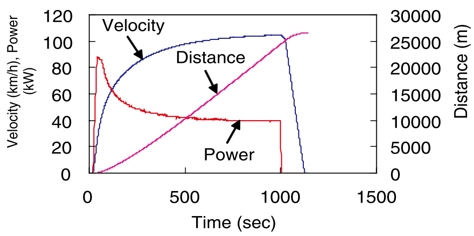

Fig. 4 Results of traction test on platform

Table. 1 Evaluation of fuel consumption and efficiency

	Maximum speed	Maximum output	Running distance	Running time	Fuel consumption	Efficiency
	km/h	kW	m	Min	km/kg	%
Running test in yard	42.9	87	650	1.7	7.6	49.9
Traction test on platform	105	88.5	26600	18.5	34.6	52.7

Development of Sheet-Pile Foundation Combining Footing with Sheet-Piles

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1. Sheet-pile foundation

In foundation works in urban areas where the construction sites are confined or located near railways, it has become necessary to consider not just providing sufficient earthquake resistance and the bearing capacity of the foundation, but also economics, work efficiency and consideration for the environment (reduction of noise, vibration and industrial waste).

A sheet-pile foundation is one that combines a spread foundation with sheet-piles used for earth-retaining works during excavation (Fig. 1 (b)). It falls between the spread foundation and the pile foundation. With this type of foundation, it is expected that the sheet-piles will enhance the enclosure of the ground immediately under the footing (ground constraining effect), increase bearing capacity of the ground by their skin friction and improve the horizontal seismic resistance of the foundation. In addition, the sheet-pile foundation eliminates the need to remove the form work from around the footing and pull out the sheet-piles after completion of the foundation work. Furthermore, the sheet-pile foundation permits a redution in the amount of soil to be excavated since it requires a smaller area of excavation. Unlike a pile foundation, a sheet-pile foundation does not require pile driving work, and hence it is economical and easy to construct. It is also friendly to the environment since it produces neither sludge nor muddy water during excavation.

2. Verification experiment using full-scale models

With the aim of confirming the workability of the sheet-pile foundation and the horizontal resistance of the foundation during an earthquake, full-scale bridge pier models, one with a spread foundation and the other with a sheet-pile foundation, were constructed and subjected to a full-scale horizontal loading test in which test loads were applied to the tops of the bridge piers. Assuming that the pier models were for an elevated single-track railway bridge 6 m in height, the footing was set at 3.6 m square and the sheet-piles were embedded to a depth of 3.5 m from the surface of the ground. The sheet-pile foundation being constructed is shown in Fig. 2. Anchor bars were welded to the sheet piles so that the sheet piles and the footing were joined. To make the footing and concrete into one unit, anchor bars were welded to the sheet-piles.

At the points upon which the force of inertia of the girders acts during an earthquake, the test loads were applied horizontally at a height of 6.5 m from the bottom of the footing. Fig. 3 shows a scene from the loading test, and Fig. 4 shows the relationship between horizontal load and horizontal displacement (P-δ curve). The sheet-pile foundation displayed seismic resistance about four times greater than the spread foundation.

3. Future prospects

Concerning the economics of the sheet-pile foundation, it can be expected that the cost of foundation work will be cut by about 20% for sandy ground with an N-value of approximately 20. In addition, the construction period could be shortened significantly. This type of foundation has already been applied in some 20 projects. It will become more widespread in the future. As a method of reinforcement of seismic resistance, it can be applied not only to new structures but also to existing ones.

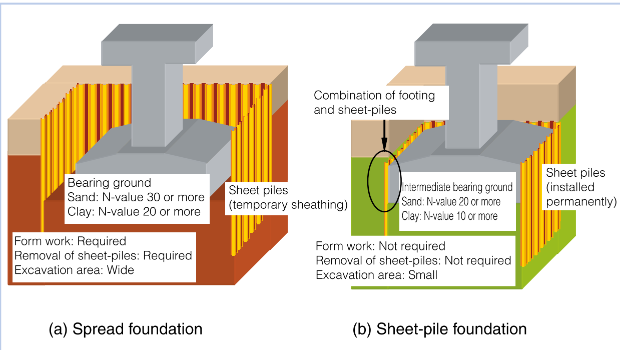

Fig. 1 Spread foundation and sheet-pile foundation

Fig. 2 Assembly of footing reinforcing bars

Fig. 3 Loading test

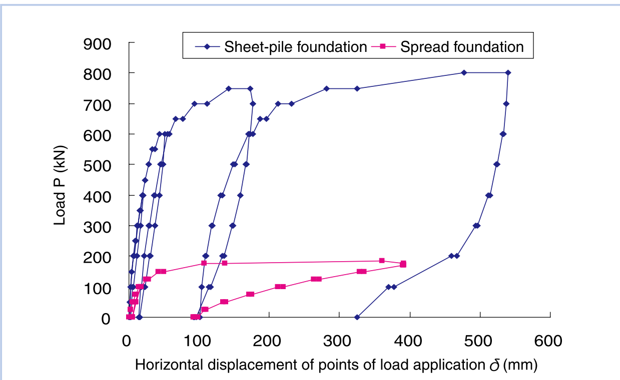

Fig. 4 Load-horizontal displacement relationship (P-δ curve)