Monotonic And Cyclic Lateral Behaviour Of Helical Pile Specialized Connectors

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Abstract:

The helical pile is a foundation system used to support new residential and commercial buildings, and to stabilize repairs of existing structures. It also represents an attractive alternative to upgrade the seismic resistance of existing foundations. This paper is part of a comprehensive study to assess the seismic performance of foundations supported by helical piles. The paper presents an experimental study conducted to evaluate the seismic performance of the specialized connectors, linking the pile shaft to the concrete foundation, in the lateral direction. The paper also presents a simplified model that can be used to account for the connector behaviour while conducting seismic analysis of structures supported by helical piles.

Keywords: Helical Pile, Specialized Connector, Experimental, Seismic, and Analytical Model.

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Introduction

Foundations represent a vital structural element to transfer the load of a structure to the underlying soil strata. Improper soil investigation and/or inadequate consideration of seismic activity are among the factors that necessitate rehabilitating an existing foundation. Other factors may include heave, soil expansion, and slope stability problems.

Although screw or helical piles had been used in practice for almost a century, they were discovered as a repair or a retrofitting tool for geotechnical and foundation applications fifteen years ago. They are considered an efficient retrofit technique for moderately loaded buildings [1]. A typical helical pile is shown in Fig. 1 and consists of a steel shaft and a number of helical plates welded to it. Various plate sizes and shaft cross-sections are available in the market. The number and dimensions of the helical plates as well as the diameter of the steel shaft can be calculated based on the required capacity and properties of the soil [3, 4].

Helical piles are typically attached to existing foundations using a two-piece specialized connector, shown in Fig. 1. It consists of a vertical bracket, a T-pipe, two-7/8" (22.2 mm) lifting bolts, and one-5/8" (15.9 mm) cross bolt. It is designed to transfer downward vertical loads (pile in compression) through bearing of the foundation on the vertical bracket leg. In any other loading direction, the connector behaviour is expected to be dependent on the performance of the two-1/2" (12.7 mm) by 4.25" (108.0 mm) wedge bolts connecting the vertical bracket to the concrete foundation. For seismic applications, the use of a three-piece connector, Fig. 2, which utilizes an uplift bracket to enhance the uplift capacity, is recommended. Five-5/8" (15.9 mm) by 7.5" (190.5 mm) wedge bolts are typically used to connect the uplift bracket to the concrete foundation.

The helical pile connectors are expected to have different characteristics in the three principal loading directions (pullout, lateral, and vertical) shown in Fig. 3. Although these characteristics may govern the effectiveness of the helical pile and its performance as a retrofitting tool, available studies have been concerned with the performance and capacity of the helical pile itself.

The monotonic and cyclic behaviour of helical pile connectors in the vertical direction was experimentally evaluated by Youssef et al. [5]. In this paper, the performance characteristics of the three-piece specialized connectors when subjected to loads in the lateral direction are defined experimentally. They include: capacity, stiffness and cyclic behaviour. The experimental results are then utilized to formulate a simplified model that can be used to predict the performance of these connectors when subjected to a lateral load.

2. Foundation Specimens

Four plain concrete foundation specimens were constructed and tested as part of this study. The dimensions of these specimens were 1.00 m by 0.60 m by 0.20 m. A mechanical vibrator was used during pouring the concrete to ensure a homogenous section that is free from voids and honeycombing. The surface of the specimens was covered after casting using a polyethylene sheet for forty-eight hours after which the formwork was dismantled and the specimens were covered by wet burlap for four days. The average concrete compressive strength at the time of testing the foundation specimens was 35 MPa.

3. Installation of Helical Pile Connectors

The connectors tested in this study were manufactured by Hubbell Power Systems, Inc., Centralia, Missouri and were composed of three pieces: C150-0121 vertical bracket, C150-0227 uplift bracket, and E150-0102 T-pipe. The following steps were used to install them.

(1) The concrete specimens were slightly chipped at their edge to ensure that the bracket is fitting flush against the edges of the concrete. Ensuring such position of the vertical bracket minimizes the eccentricity of the load on the helical piles and thus increases the capacity of the helical pile [6].

(2) The vertical and the uplift brackets were placed on the surface of the concrete and used as templates for drilling seven holes, two of them with 1/2" (12.7 mm) drill bit and the rest with 5/8" (15.9 mm) drill bit.

(3) Two-wedge bolts size 1/2" (12.7 mm) diameter by 4.25" (108.0 mm) length were used to connect the vertical bracket to the concrete foundation; and five-wedge bolts size 5/8" (15.9 mm) diameter by 7.5" (190.5 mm) length were used to connect the uplift bracket to the concrete foundation. The wedge bolts were driven into the concrete by hammering and then the nuts were tightened to the torques specified by the bolts manufacturer, which were 55 lb.ft. (74.6 N.m.) for 1/2" (12.7 mm) bolts and 90 lb.ft. (122.0 N.m.) for 5/8" (15.9 mm) bolts. It should be noted that the bolts connecting the vertical bracket to the concrete specimen were not installed at the same position in all specimens. This was done to simulate the actual field condition where the vertical and the horizontal clearance around these bolts will lead to similar conditions.

4. Test Setup

The setup, shown in Figs. 4, 5, and 6 was designed to simulate the lateral load transferred from the foundation to the helical pile during a seismic event. It is characterized by:

(1) Three clamping beams prevented the uplift movement of the concrete specimen. Each beam was held to the rigid floor using two steel rods.

(2) The rigid floor of the structures laboratory prevented the downward movement of the blocks.

(3) Two steel angles prevented the side sway movement of the concrete block.

(4) To transfer the load from the MTS actuator to the T-pipe, a specially designed loading shaft was connected to the MTS actuator from its threaded end. Its opposite end was connected to a lateral loading assembly. The ring of the lateral loading assembly was placed around the T-pipe at a distance of 200 mm from the concrete block, as shown in Figs. 5 and 6. When the MTS actuator was displaced, the ring moved freely until it came in contact with the pipe. The pipe resisted further displacements until failure occurred.

(5) Fig. 5 shows the locations of the Linear Voltage Displacement Transducers (LVDTs). Five LVDTs (1, 2, 3, 4, 5) were used to monitor the movement and rotation of the concrete block. Their measurements were used to correct those of the LVDTs monitoring the lateral movement of the T-pipe (8), the vertical bracket (7), and the uplift bracket (6).

5. Loading

The loading was provided by a 1500 kN hydraulic jack with a maximum stroke of 160 mm. A load cell with maximum capacity of 245 kN was used to record the actuator readings. Two types of tests were conducted:

5.1. Monotonic Load Tests:

A displacement controlled approach was used where the displacement was incrementally increased with a rate of 1 mm /minute. These tests were conducted to define the static behaviour of the specialized connectors.

5.2. Cyclic Load Tests:

A displacement-controlled approach was used to apply several cycles of loads. In each cycle, the actuator was first pushed to a displacement d1 in the positive direction then pulled to the same displacement d1 in the negative direction. The value of d1 was incrementally increased in the following cycles. It should be noted that this type of loading is static in nature and does not capture the effect of high loading rates that are expected during earthquakes. Such high loading rates are expected to result in a higher capacity and thus the results of the conducted tests are considered to represent conservative evaluation of the seismic behaviour of the connectors [7].

6. Monotonic Behaviour

In this section, the monotonic behaviour of the three-piece connector is examined by conducting two tests. The first test (L1) was characterized by having a hollow T-pipe. Figure 7 shows the lateral load-displacement relationship for the T-pipe (LVDT #8). The behaviour was governed by the combined stiffness of the T-pipe, the vertical bracket, and the uplift bracket.

- For loads less than the yielding load of the T-pipe that was estimated to be 8 kN, the behaviour was governed by the elastic bending stiffness of the T-pipe.
- At a load of about 8 kN, the T-pipe started to yield and its stiffness started to decrease. This continued until reaching a load of about 12.5 kN at which the T-pipe started to bear on the stiffener of the vertical bracket. This resulted in a slight increase in the overall stiffness.
- At a load of about 25 kN, the leg of the vertical bracket became fully bearing on the concrete surface and the vertical bracket stiffness was fully utilized. This explains the increase in the overall stiffness observed at this load.

- At a load of about 34 kN, one of the wedge bolts connecting the vertical bracket to the concrete specimen failed. This led to a free rotation of the vertical bracket.
- At a deformation of about 42.5 mm, the uplift bracket prevented this rotation and increased the overall stiffness.
- the test was terminated at a deformation of about 51 mm because the hydraulic jack reached its maximum stroke.

In the second test (L2), a portion of a helical pile shaft was inserted inside the T-pipe and fixed in position by using epoxy raisin, as shown in Fig. 8. This simulated the field conditions. The hydraulic jack was moved to its mean position to allow achieving greater deformations than that of test L1.

Figs. 7, 9, and 10 show the total load-deformation curves obtained in this test for the T-pipe (LVDT 8), the vertical bracket (LVDT 7), and the uplift bracket (LVDT 6), respectively. From these curves, the following observations can be made:

- The initial behaviour was similar to that described in test L1. The main difference was that the vertical bracket became fully bearing on the concrete specimen at an earlier Load. This can be attributed to the difference in the clearance around the bolts and between the vertical bracket and the concrete specimen. Such a difference is expected in field installations. It should be noted that the composite section, shown in Fig. 8, had minor effect on the initial stiffness.
- The observed deformations in the uplift bracket, Fig. 10, are very small compared to those of the vertical bracket, Fig. 9, and the T-pipe, Fig. 7. This could be attributed to its high lateral stiffness provided by the five wedge bolts connecting it to the concrete specimen.

- Similar to test L1, a bolt failure was observed at a displacement of about 38 mm. This was followed by a free rotation of the vertical bracket that was prevented by the uplift bracket.
- Relocating the hydraulic jack enabled continuing the test until the specimen failed at the weld connecting the T-pipe and its flanges at a displacement of 68 mm.

The two tests L1 and L2 gave similar performance suggesting that the addition of helical pile shaft and the epoxy raisin did not contribute to the overall stiffness and strength of the system. For modelling the lateral behaviour of the specialized connectors, it is suggested to use a linear spring element with stiffness 0.87 kN/mm and ultimate strength 34 kN.

7. Cyclic Behaviour

Two tests (L3 and L4) were performed in this section. In both tests, the specimens were fitted with the helical pile shaft and the epoxy raisin to match the field conditions. A number of load cycles with an increase in the total displacement amplitude of 2 mm between successive cycles were applied to each specimen.

Figures 11 and 12 show the load displacement relationship for the T-Pipe for tests L3 and L4, respectively. Both specimens behaved in a similar fashion showing low energy dissipation and high pinching behaviour. The failure load was about 45 kN, which is higher than the monotonic failure load. Also, the failure mechanism was different from that observed in the monotonic tests as no bolts failure occurred and failure was at the weld connecting the pipe to its flange. The differences between the monotonic and cyclic tests might be attributed to the variability incurred in positioning the vertical bracket and its bolts.

The deformations of the vertical and uplift brackets in test L3 are shown in Figs. 13 and 14, respectively. The Figures show that the contribution of the uplift bracket to the total deformation is minor relative to the contribution of the vertical bracket and the T-pipe.

The load-deformation results of tests L3 and L4 were analyzed to develop a simplified model that can be used in finite element analysis to predict the cyclic behaviour of the connectors. This led to the force-displacement curve shown in Fig. 15. The dots in this figure illustrate the experimental envelope curves for both tests. The model is characterized by linear envelope curves in tension and compression. Unloading from a displacement d1 on the tensile or compressive branches would be aiming at displacement 0.72 d1 on the displacement axis. Unloading will then proceeds on the horizontal axis until reaching zero deformation. At this point, loading in the other direction starts. Although the observed failure load in the cyclic tests is 45 kN, it is recommended to limit the failure load to 34 kN which is the value observed in the monotonic tests.

8. Summary and Conclusions

In this paper, the performance of helical piles brackets when subjected to lateral loading simulating the lateral loading component of an earthquake is assessed experimentally. The brackets were installed using the same procedure implemented in the field. Based on monotonic and cyclic loading tests, the following conclusions were made:

8.1 Monotonic behaviour:

- The observed failure mechanism was wedge bolt shear failure followed by failure of the weld connecting the T-pipe to its flanges.

- The helical pile shaft and epoxy raisin installed in the T-pipe does not affect the lateral performance of the helical pile connector.
- Lateral deformations of the helical pile connector are mainly due to the movement of the vertical bracket and the T-pipe.
- The connector can be modelled as a linear spring element with stiffness 0.87 kN/mm and ultimate strength of 34 kN.

8.2 Cyclic behaviour:

- The connector failed at the weld connecting the T-pipe and its flanges. The failure is different than that observed in the monotonic tests mainly due to the variability in placing the vertical bracket and the bolts connecting it to the concrete foundation. This suggests a need to modify the bracket design or the installation methodology to reduce this variability.
- The connector can be modelled as a spring element. The proposed force-displacement relationship to be used is shown in Fig. 15. It is recommended to limit the failure load to 34kN.

It should be noted that the suggested analytical models are only valid for the connectors tested in this study. If different connectors are to be used, an experimental investigation must be conducted to judge the validity of the proposed models and to calibrate them, if needed.

10. References

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List of Figures:

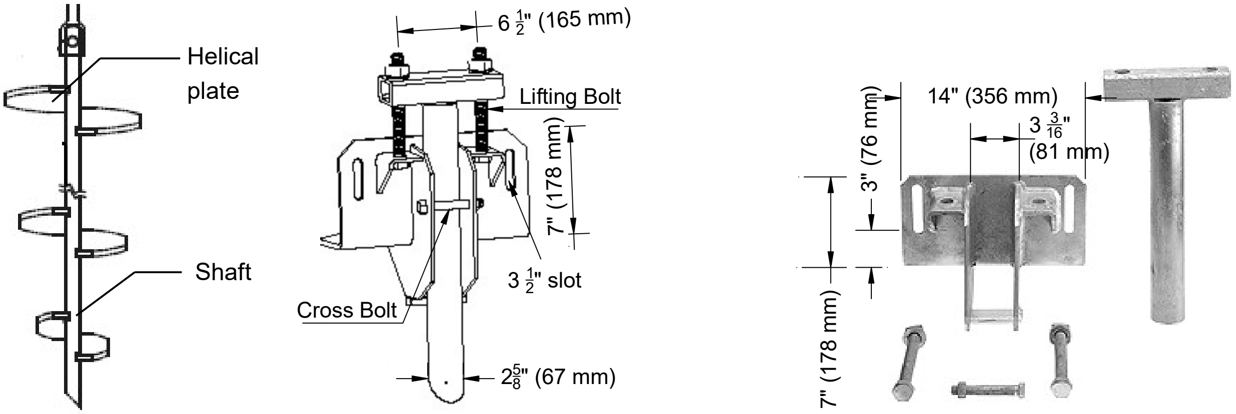

Fig. 1. a Helical Pile and a Two-Piece Specialized Connector [2]

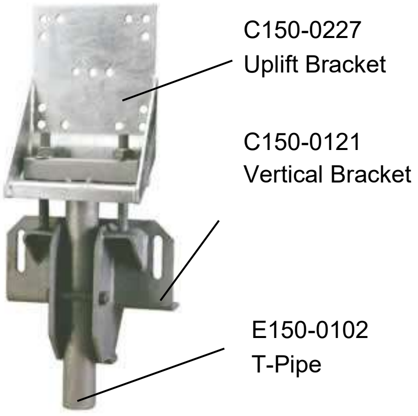

Fig. 2. Three-Piece Helical Pile Connector

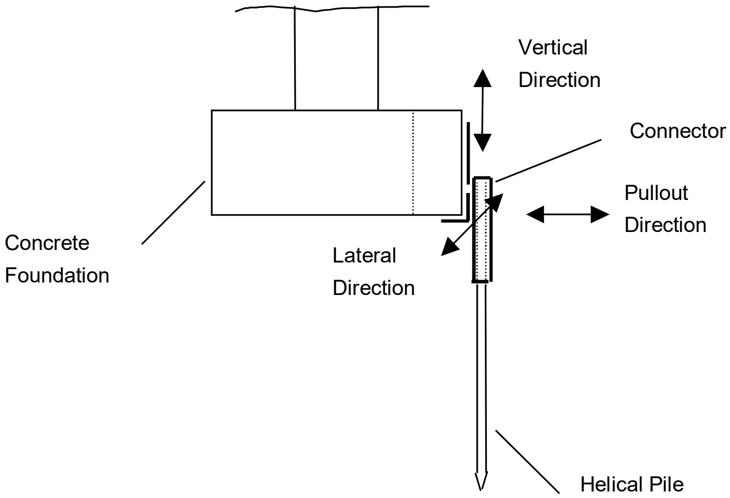

Fig. 3. Typical Helical Pile After Installation

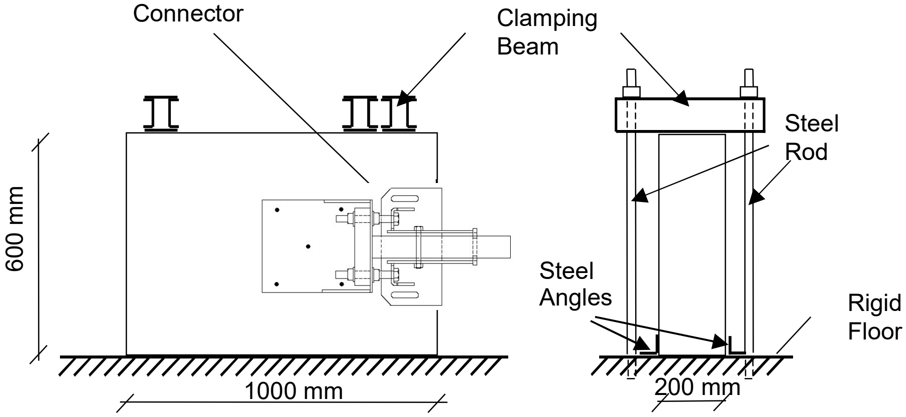

Fig. 4. Test Setup

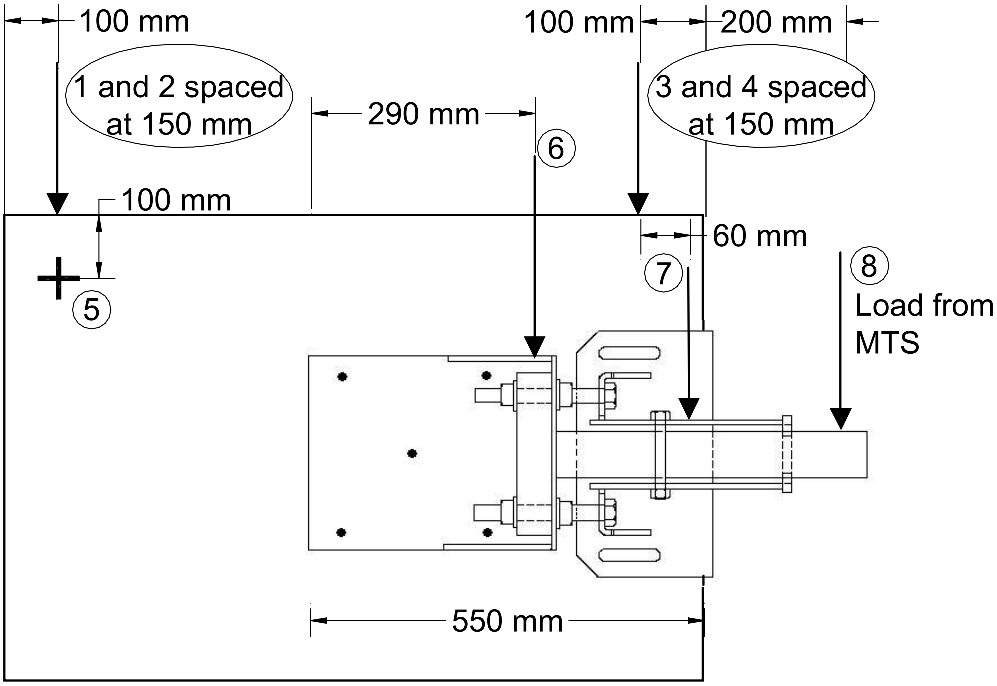

Fig. 5. Displacement measurements using LVDTs

Fig. 6. Photo of the Test Setup

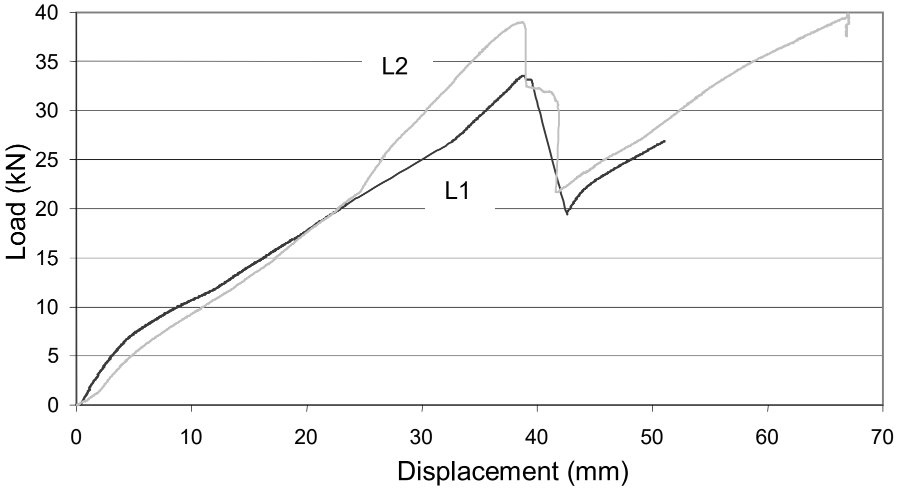

Fig. 7. Monotonic Lateral Load-Displacement Relationship for T-Pipe (Tests L1, and L2)

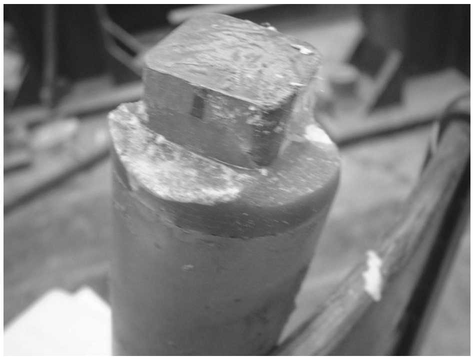

Fig. 8. T-Pipe Composite Section

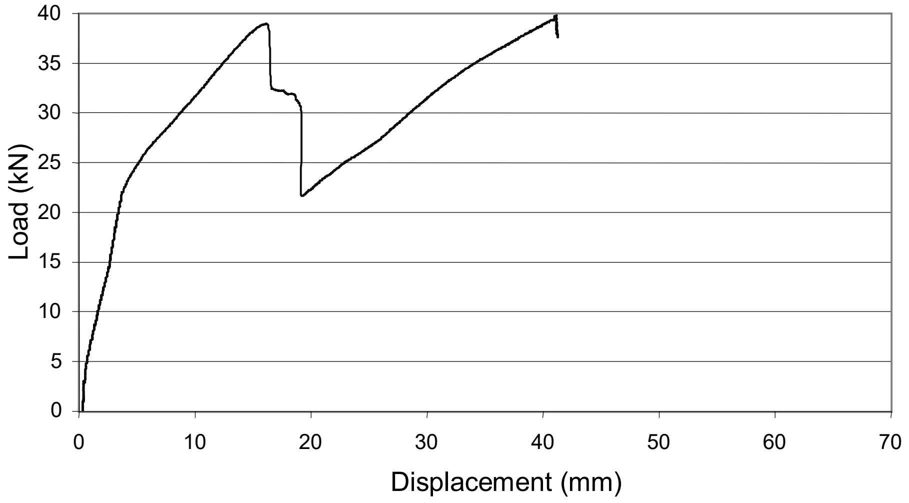

Fig. 9. Monotonic Lateral Load-Displacement Relationship for Vertical Bracket (Test L2)

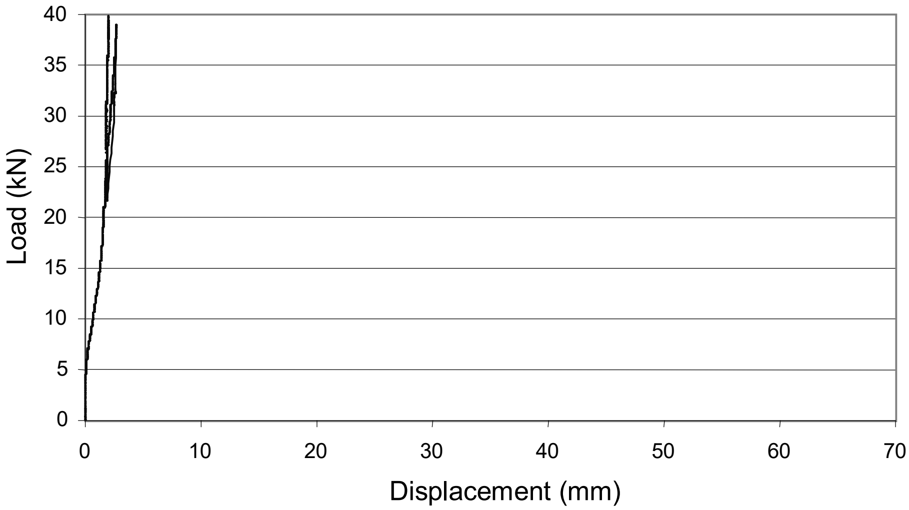

Fig. 10. Monotonic Lateral Load-Displacement Relationship for Uplift Bracket (Test L2)

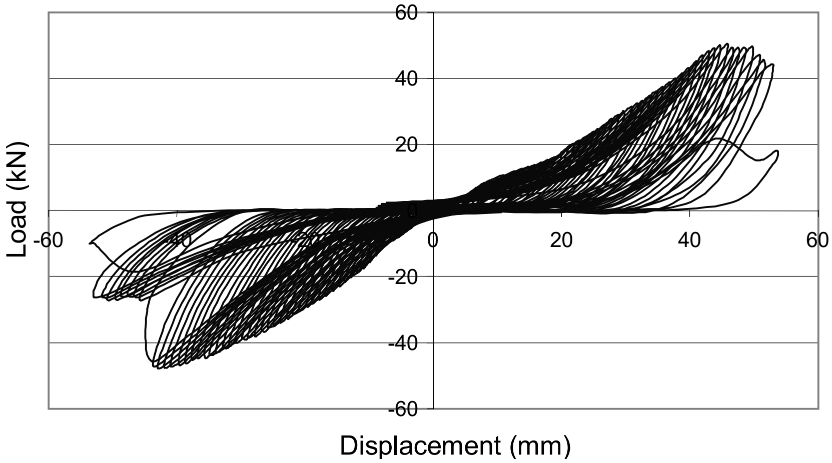

Fig. 11. Cyclic Lateral Load-Displacement Relationship for T-Pipe (Test L3)

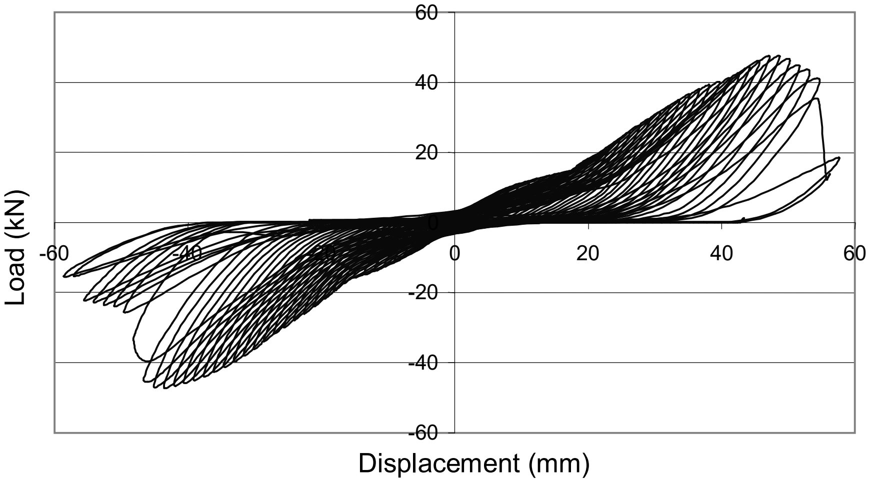

Fig. 12. Cyclic Lateral Load-Displacement Relationship for T-Pipe (Test L4)

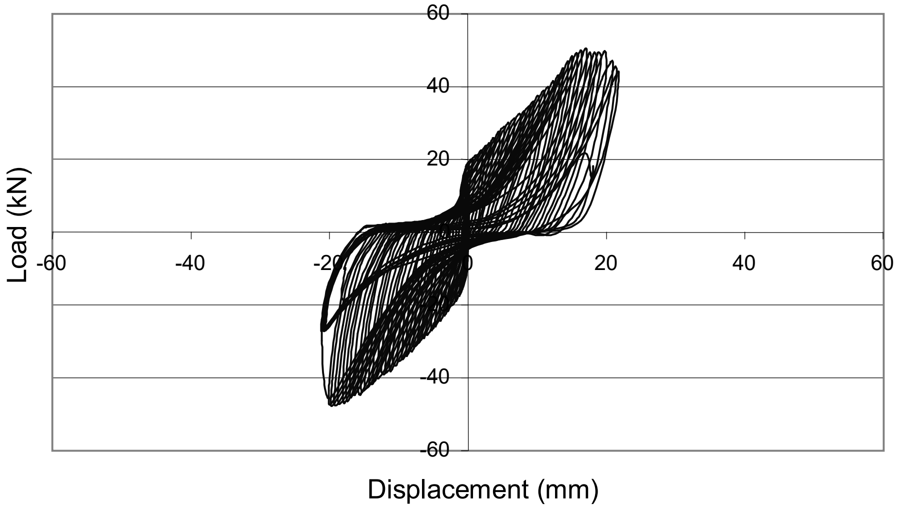

Fig. 13. Cyclic Lateral Load-Displacement Relationship for Vertical Bracket (Test L3)

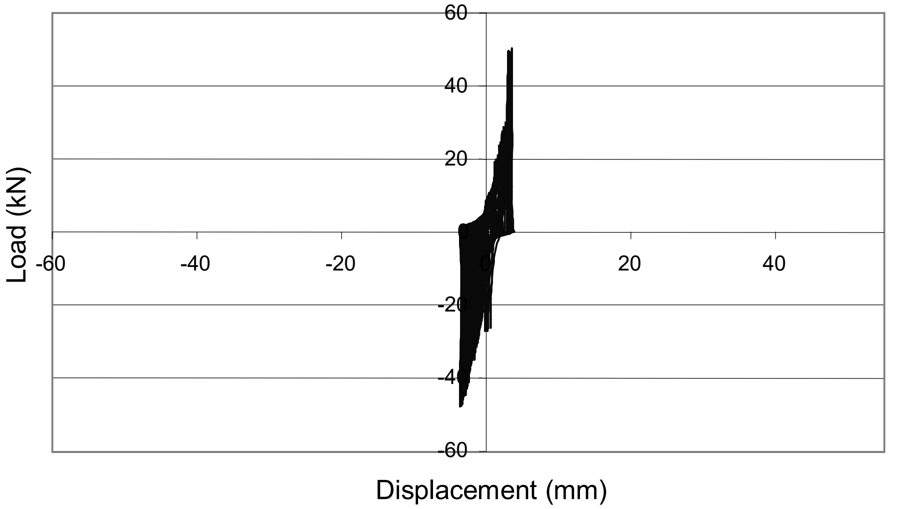

Fig. 14. Cyclic Lateral Load-Displacement Relationship for Uplift (Test L3)

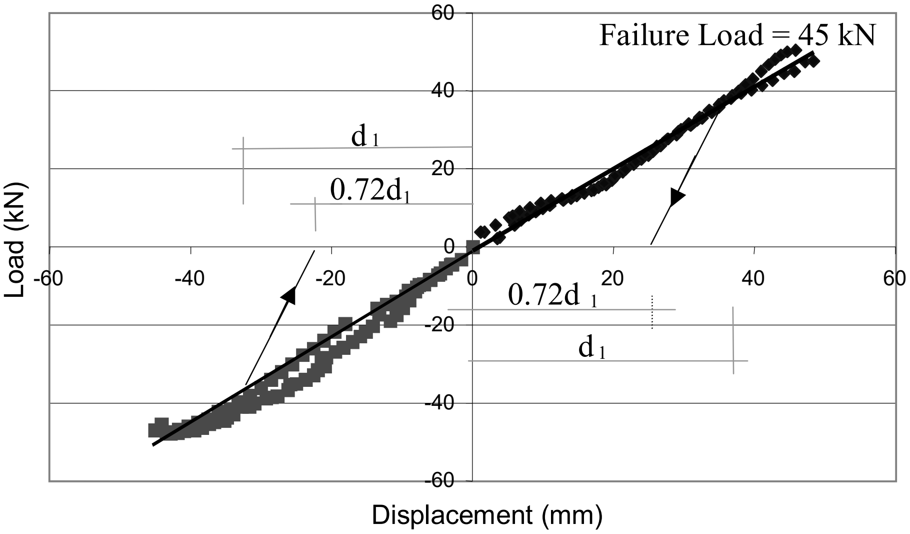

Fig. 15. Proposed Cyclic Model