Bi-directional Static Pile Load Test by S-Cell Method

Vijay Kumar Patidar, Suneet Kaur and Nitin Dindorkar

Abstract Static load testing is a conventional technique for testing pile in which loads are applied on the top of the pile and generally known as 'top-down testing'. This has been in practice from many years all over the world and has become a standard test for pile foundation. This method cannot be used when there is lack of space and high magnitude of load is to be applied for the pile test. There is a finite limit to the load capacity that can be applied with either kentledge, the use of reaction piles, or anchors, and as the load increases, the costs of whole assembly also increases. An attempt has been made in this study to adopt a new technique which would overcome all the large-scale problems associated with top-down testing technique. This method will divide the pile into two or more sections, and these can be loaded axially as required using a portion of the pile element as a reaction. Bi-directional static pile load test (S-Cell method) is economical and less time-consuming test as compared to conventional static load test. Therefore, bi-directional static pile load test can be considered as an alternative test for heavily loaded pile foundation in India.

Keywords Load test · Bi-directional static load test (BDSLT) · Super cell · S-Cell · Foundation engineering · Equivalent curve

1 Introduction

Testing of pile plays an important role for the optimization of the pile design from a geotechnical point of view. Static load testing, where loads are applied vertically to the top of the pile and often referred to as 'top-down testing', has been used for many years and has become a 'standard' test for the world of foundation engineering. Bi-directional pile load test method attempts to overcome all the associated problems of conventional top-down static load testing techniques. The Super cell (S-Cell) load test is a bi-directional, axial, compressive, static load test conducted on deep foundations

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to evaluate the soil–pile resistance [1]. This paper attempts to highlight some of the advantages of S-Cell over the conventional methods in Indian scenario.

2 Bi-directional Pile Testing Using S-Cell

2.1 About S-Cell

The S-Cell is a high-pressure hydraulic jack installed on the rebar cage and embedded into the foundation under test. The shaft above and below the S-Cell provides reaction for loading. The hydraulic working fluid is water for simplicity and environmental safety. If used in working pile, the S-Cell can be easily grouted after test completion. Multiple sizes of S-Cell are available based on test load capacity of the Pile. Any loading capacity is achieved by applying limited pressure up to 30 MPa by combining S-Cell in series as per the requirement. Each S-Cell is assembled in India and calibrated in-house for quality and reliability.

2.2 Method of Operation

In the conventional top-down testing, when load is applied at the pile head via a reaction system known as kentledge, force (P) is applied downward to the pile. All of the load measured at the pile head is applied to the pile which is equivalent to the sum of mobilizing skin friction (F) and the end bearing (Q), $P = F + Q$ (Fig. 1).

When S-Cell is installed at the toe of the pile, the load is transferred directly to the end bearing. The base resistance is used to mobilize the skin friction and vice versa. Therefore, the skin friction and the base resistance mobilized are equal until one or the other reaches ultimate capacity or the S-Cell system exceeds its capacity, i.e. $P = F = Q$ (Fig. 1).

When the skin friction ($F1 + F2$) is expected to be higher than the base resistance, the S-Cell can be placed at some balance point along the pile shaft where $P = F1 = F2 + Q$. The pile element above the S-Cell uses the friction ($F2$) and end bearing (Q) below as a reaction (Fig. 1).

2.3 Installation of S-Cell

The S-Cell is calibrated before installation and provides an axial compressive load test as the jack is pressurized from the surface. Assembly is installed into the pile cage or carrying frame, either at or close to the pile toe or along the shaft at a level

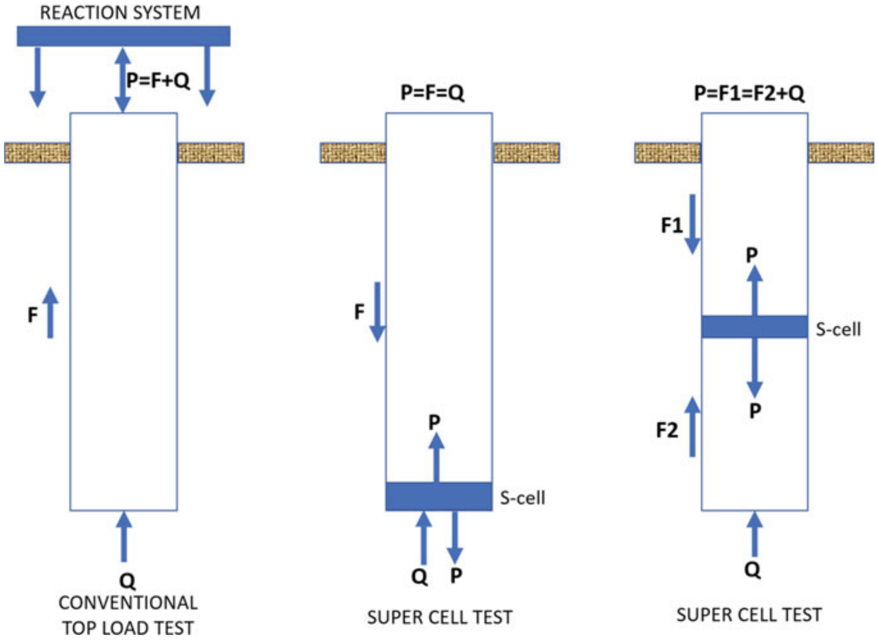

Fig. 1 Test method comparison

where approximately equal capacity will be available above and below known as balancing point as explained in the previous section.

During the construction of pile, the cage of reinforcement is placed in the pile bore with S-Cell assembly welded during cage preparation as shown in Fig. 2. Strain gauges installation and hydraulic connections are made and cables and hoses are brought up to the pile head. A guide arrangement is constructed for insertion of the tremie into position wherever needed. Concrete is then pumped into the pile shaft and around the S-Cell assembly with proper pressure to avoid voids.

2.4 Testing Procedure

In conventional method 'top-down' testing, the safety considerations are very challenging, especially at high loads as very huge kentledge and reaction beam assemblies are needed to be assembled. In contrast to conventional method, bi-directional testing has all reactions generated from within the pile itself. The area required for testing work in both overhead and lateral direction is reduced drastically as compared to any other static load testing methods. Testing can be performed in limited space adjoining buildings, overpasses, and also at offshore locations.

Fig. 2 Installation of S-Cell assembly in cage of diameter 1.5 m for test pile at foot over bridge construction in Sabarmati Riverfront Ahmedabad, Gujarat, India

Figure 3 shows the schematic diagram of S-Cell installation with the instrumentation provided for test. Figure 4a and 4b shows that on field these instrumentations need very less test areas, which are slightly more than the perimeter of pile shaft. Embedded jack assembly is used to apply the load on test pile. The resulting test load applied to the pile is twice the load measured in the jack assembly (Fig. 1). Structural capacity of the pile or the jack assembly should not be exceeded.

To avoid excessive creep and possible structural failure of cast-in-place concrete piles, the concrete should generally achieve uniform strength throughout the pile and should be at least 85% of the mix design compressive strength. Prior to performing the test, hydraulic fluid should be circulated through each jack to verify connectivity, saturate the system, and flush any blockages. Reference beam and LVDTs are set up in the tent to protect them against wind and heat.

Loading may be sustained or continued for a longer time interval to asses long-term creep and rebound behaviour after full unloading. Displacements are measured at each load increment intervals using LVDTs attached to reference beam. The readings can be displayed graphically as the test progresses. Thus, load/displacement data recorded above and below the S-Cell level is available for analysis (as that illustrated in Fig. 5). All the stored data will be analyzed after end of the test to calculate load

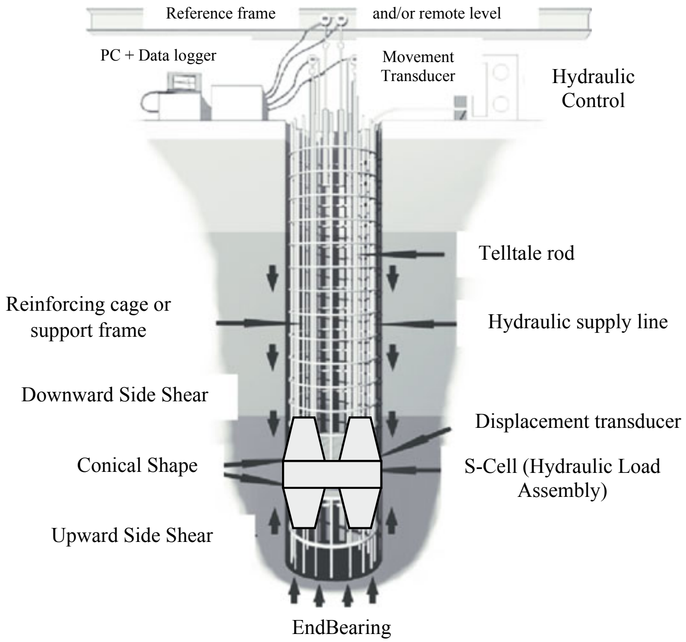

Fig. 3 Single-level S-Cell schematic diagram

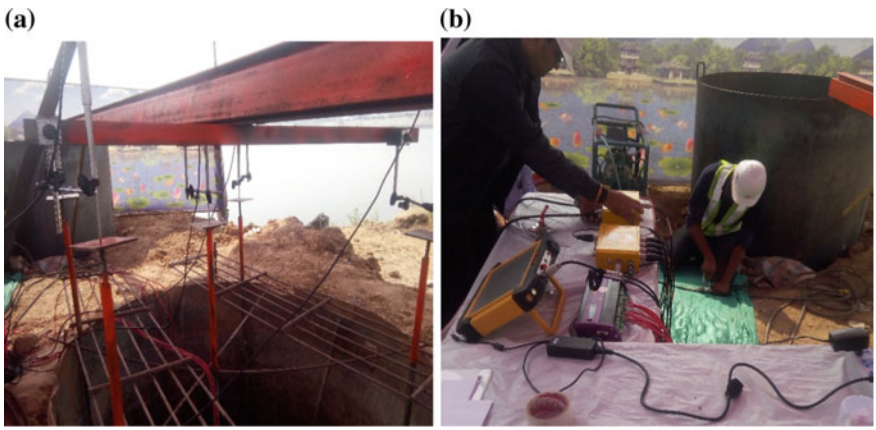

Fig. 4 Assembled setup for bi-directional static load test. **a** LVDT's with reference beam. **b** Data logger, data taker, control box, and pressure pump are connected together

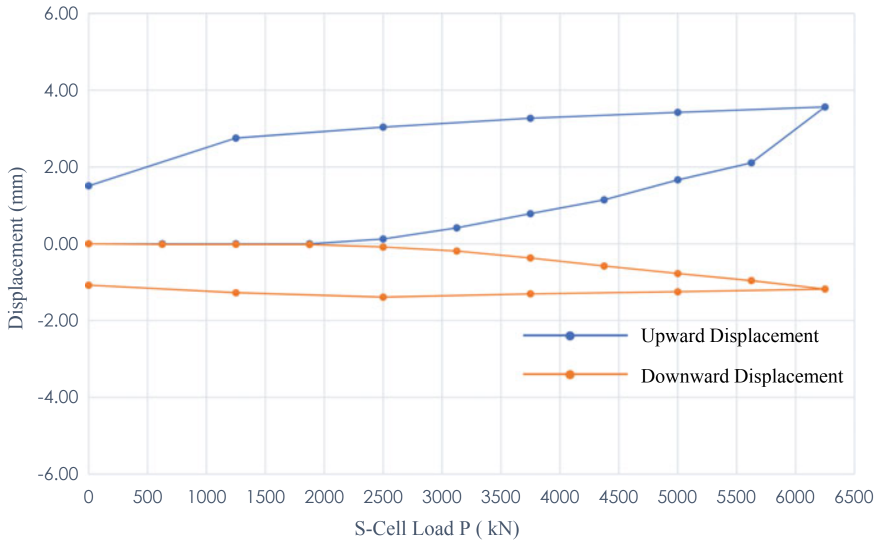

Fig. 5 S-Cell load versus displacement curve

distribution at strain gauge levels, ultimate skin friction, and end bearing at failure load or at maximum test load, for drawing equivalent top-load movement curve.

The total load mobilized in the pile is twice of that applied by the S-Cell system because the load is applied in two opposite directions (bi-directional) simultaneously. Self-weight (including buoyant force) of the pile is considered during calculation of balancing point. Therefore, the stresses within the concrete are half of the required stress by an equivalent top-down load test. Detailed analysis of the soil properties along the pile shaft can be done by embedded strain gauges or other devices.

2.5 Conversion of BDSLT Curve into Equivalent Top-Down Curve

Upward (Q^{+} vs. s^{+}) and downward (Q^{-} vs. s^{-}) curves from bi-directional static load test (BDSLT) need to be converted into conventional load–deformation curves (Q–S curve) as shown Fig. 6 [2].

Conversion of pile top load versus displacement between BDSLT and conventional static test is based on synchronization principle of upward and downward displacement. Equivalent pile top load and pile top displacement after conversion can be computed by the formula as shown below.

$$Q = \left[(Q_{\mathrm{u}} - W)/\gamma\right] + Q_{\mathrm{d}} \quad (1)$$

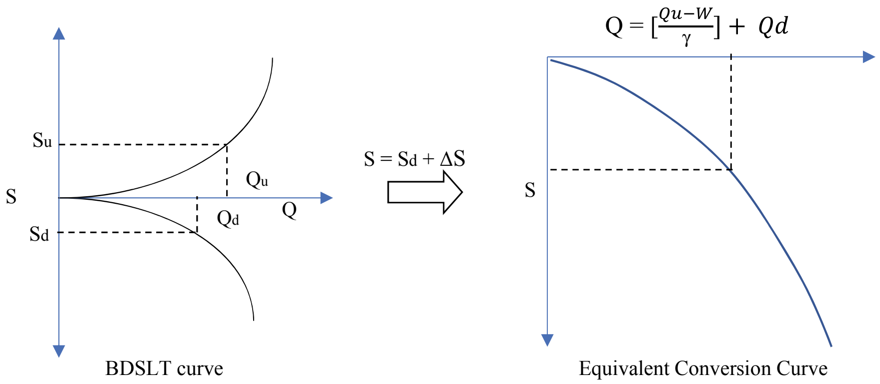

Fig. 6 Conversion of BDSLT curve into equivalent top-down curve

$$S = S_d + \Delta S \tag{2}$$

where

- Q is equivalent pile top load after conversion
- Q_u Upper pile load when upper pile displacement absolute value equal to S_u in Q_u versus S_u curve, unit is kN
- W Test pile upper pile self-weight above load cell, unit is kN
- γ Correction factor; soil = 0.8, sand = 0.7, rock = 1.0
- Q_d is downward load value of the cell
- S is pile top displacement after conversion
- ΔS is pile shaft compression, S_d is downward displacement.

Upper pile compression ΔS is equal to the sum of elastic compression caused by upper pile and lower pile:

$$\Delta S = \Delta S_1 + \Delta S_2 \tag{3}$$

where

- ΔS_1 Elastic compression caused by the vertical load of the bottom compressed pile;
- ΔS_2 Elastic compression caused by friction resistance of the upper compressed pile.

$$\Delta S_1 = \frac{QdL}{E_P A_P} \tag{4}$$

$$\Delta S_2 = \frac{(Q_u - W)L}{2E_P A_P \gamma} \tag{5}$$

$$\Delta S = \Delta S_1 + \Delta S_2 = \frac{[(Q_u - W)/\gamma + 2Qd]L}{2E_P A_P} \tag{6}$$

where

L Upper pile length, unit is m;
E_P Pile shaft elasticity modulus, unit is kPa;
A_P Pile shaft cross-sectional area, unit is m^2.

It is useful to see the results of a bi-directional load test in the form of a curve showing the load versus settlement of the pile if it were top-loaded. There are some methods to find the equivalent top movement curve but generally, the test results can be combined by adding the loads mobilized at equal displacements. Some additional parameters like elastic shortening, buoyant force, modulus of elasticity of pile along the length of pile, etc. are needed to keep in consideration for calculating equivalent top-load movement curve. A smaller number of comparisons have been made between the equivalent pile head movement and top-loading test results around the world. England [3] compared static load results between top-down loading and bi-directional testing. He showed excellent correlation between the two.

3 Advantages of Bi-directional Static Load Test Over Conventional Methods

The advantages of BDSLT are explained as follows.

3.1 High-Quality Data

Digital LVDTs and pressure transducers are used with least count 0.01 mm and 0.01 MPa, respectively to get high-quality data as these instrumentations have efficiency to record all the reading simultaneously during loading intervals.

3.2 Higher Load Limit

Lots of practical problems encountered during top-down load test, when load is more than 4 MN, i.e. approx. 400 ton [4]. Lots of space and machinery are required to make proper arrangement. By using S-Cell testing method, there is saving in terms of cost, transport, installation, and erection of kentledge, anchors, or anchor piles as well as the associated reaction system required above ground level. There is improvement in terms of safety, at the head of the pile as the assembly of a loading system is not required and the loads applied are through S-Cell embedded in the pile. The installation/welding of an S-Cell on an existing steel reinforcement cage typically takes one or two days with proper alignment. But the arrangement of kentledge for loads up to 4 MN may take over 20 days to make proper platform and reaction arrangement with help of loading blocks. These features can make it preferable over top-down static load testing.

3.3 Rock Socketed Pile

It is difficult to evaluate skin friction in rock sockets because it not possible to ensure that the load applied has reached the area of interest. In top-down tests, it is found that the skin friction is often indistinguishable from the end bearing and extra sensors within the pile body are required to evaluate the friction distribution. Bi-directional tests can be arranged to apply the load directly into the rock sockets (or other zones of interest), and thereby, the resultant behaviour is more readily interpreted.

3.4 Use of Test Pile as Working Pile

In bi-directional tests, after fully grouting in and around the cell generally, the original stiffness is reverted with increase in base stiffness behaviour up to loads more than service load. Hence, it can be safely used as working pile.

3.5 Testing Time

Bi-directional statics load test takes less time as compared to conventional top-down test; hence, it is also known as quick static load test.

3.6 Applications

In several countries, up to 1% of the piles installed are static load tested and it appears more routinely to apply loads from top to down at the pile head. However, in many circumstances, the full-scale testing using top-down testing method is obstructed and bi-directional testing is becoming conventional. S-Cell test has been performed at various projects in India including offshore sites.

3.7 Cost

The current comparison between costs of top-down and bi-directional load tests in India shows that up to 7.5 MN loading costs per MN are same in both conventional and bi-directional load tests. However, at higher loads, bi-directional tests become more cost-effective because only the cell cost increases, and the cost of instrumentation remains same. As the number of bi-directional tests increases, transportation cost and mobilization of instruments and personnel are also reduced. Hence, the overall cost of test gets reduced with increase in test load and number of tests.

4 Conclusion

(a) The execution of top-down load tests has been optimized and made as cost-effective as possible; still, there is scope for further development in the practice of full-scale foundation testing using bi-directional tests.
(b) Bi-directional static load test has unlimited loading capability, as compared to conventional techniques.
(c) There are considerable costs savings at loads above approximately 7.5 MN.
(d) Use of bi-directional S-Cell testing technique enables collection of full-scale data even under the most extreme and difficult conditions by providing significant advantages in terms of space and safety.
(e) The bi-directional test is a static load test using automatic data acquisition techniques, load maintenance for accurate, efficient data processing, and analysis for calculating skin friction and end bearing separately.
(f) The S-Cell test method excels in offshore testing environments as the top of the foundation element is not required to be cast above water.

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