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D R A F T

Subject:

On Friday July 24, 2015, I attended a static loading test at 1047 Commonwealth Ave. in Brookline (Boston) performed on a 40 ft pile equipped with an expanded or enlarged toe ("Expander Body Incotec"). The test was performed by HUB Foundation Co. of Chelmsford, Massachusetts.

The purpose of this letter is to report on the results of the test.

!. The Expander Base Incotec, EBI

The Expander Body Incotec, EBI, consists of an initially about 5 ft high and 8 inch diameter cylindrical, folded steel tube body. After placing the EBI at the end of a small diameter steel casing, or end of a reinforcing cage in a bored pile, and inserting the EBI to a desired depth, it is inflated by injecting cement grout. The final shape is nearly spherical as shown in Figure 1.

Figure 1. The EBI before, during, and at end of the inflation procedure

The lateral expansion of the EBI causes the EBI to reduce its height. Tension forces will therefore develop between the EBI and the lower portion of the casing or pile. The connection between the EBI and the pile is therefore prepared with reinforcing that prevents the damage due to the tension force. Moreover, the expansion-induce height reduction potentially results in a void below the EBI. This void is postgrouted a day or so after the EBI grouting to ensure the sound contact between the EBI and the soil below.

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2. The Soil Profile

The loading test was performed in an alley between two existing buildings founded on piles. Figure 2 shows a photo of the site during the ongoing test. The soil profile was determined in three boreholes (borehole logs by Soil Exploration Corp. dated April 24, 2014). Figure 3 shows the distribution of SPT N-indices and soil profile, as determined from visual inspection of the split-tube samples. The EBI-equipped test pile is also indicated. The groundwater table was reported to be at 23 ft depth. As no water content or soil density values were provided, a total density of 125 pcf is assumed representative for the soil profile throughout.

Figure 2. Photo of test site during ongoing static loading test

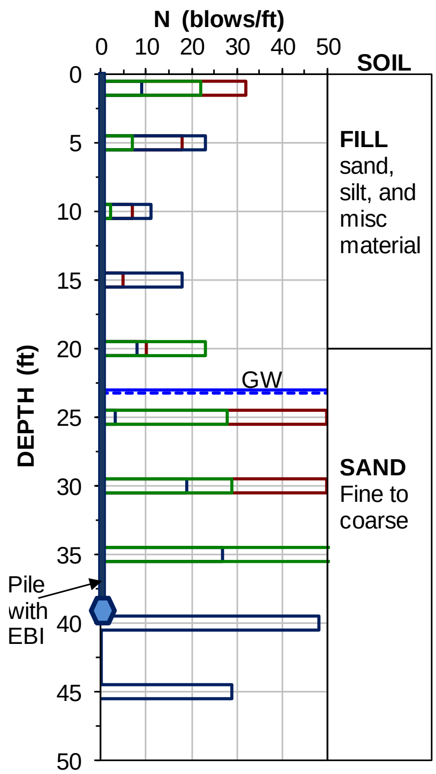

Figure 2. Soil profile and SPT N-indices

3. The Test Pile

On July 18, 2015, the test pile was constructed by rotating and pushing down a 7.0 inch casing with a 0.408 inch wall with an inside cutting bit on a pipe that simultaneously cut the soil as it collected inside the casing and flushed the cuttings upward with water. On reaching the 40-ft desired final depth, the casing was flushed clean and the cutting pipe removed. On July 20, 2015, an about 5 ft long, 24 inch wide EBI attached to a 3.5-inch injection pipe with a to a 0.230-inch wall was inserted into the casing to the final embedment depth. The top of the EBI was attached to a 5 ft long, 5.5-inch diameter connection pipe with a 0.415-inch wall. A base-grouting pipe was connected to the injection pipe and extended to the bottom plate of the EBI. Two 1.5-inch wall 0.25 inch telltale guide-pipes were also attached to the 3.5-inch injection pipe to depths of 35.8 and 38.3 ft, respectively, i.e., at the top of the EBI and 2.5 ft down into the EBI, respectively. The telltales were arranged to measure movement. The steel areas of the 7.0-inch casing, the 3.5-inch injection pipe, the 5.5-inch connection pipe, the 0.5-inch base-grouting pipe, and each 0.5-inch guide pipe were 8.45, 2.36, 6.63, 0.20, and 0.20 in^2, respectively. **[dimensions of base-grouting pipe and guide pipe to be confirmed].**

Prior to inserting the injection pipe, three vibrating-wire strain-gages, SG1, SG2, and SG3 (sister bars of 0.5-inch diameter—i.e., 0.2-inch area) had been attached to the pipe so as to be placed inside the casing at depths of 4.0, 9.2, and 29.0 ft, respectively. After installing the injection pipe with telltales, connection pipe, base-grouting pipe, guide-pipes, and sister bars, a 0.5-inch PVC tremie tube was inserted to the top of the EBI. After capping the casing, concrete **[cement grout?]** was injected to the top of the EBI applying a pressure of 100 psi to force the concrete to flow up inside the casing. On completing the tremie, the cap and the tremie pipe were removed and the concrete topped up. The casing was then lifted up 1.5 ft to allow for the EBI to be inflated/expanded and the EBI was expanded using cement grout injected at 2.0 MPa (290 psi) pressure. The next day, July 21, the base-grouting pipe was used to pressure-grout the zone below the EBI applying a 1.2 MPa (170 psi) pressure.

The total cross sectional area of the pile was 38.7 in_2. The total steel area in the pile at the gage levels (SG1 andSG2) was 11.6 in^2, the balance, 27.1in^2 being concrete.

4. The Test Arrangement

The static loading test was performed by jacking against a beam connected to the reaction piles installed prior to constructing the test pile placed about 8 ft on each side of the test pile. The pile head movement was measured using two dial gages and the telltale movements were measured using one dial gage for each telltale top. Figure 3 shows the telltale arrangement at the pile head. A load cell was used to measure and record the load applied to the pile head.

Figure 3. Arrangement of dial gages at the pile head

The test procedure was according to the ASTM SD1143 guidelines for the quick, maintained load method applying load increments determined as 1/20 of the maximum load (22.2 kips corresponding to 350 psi on the jack pressure) of the reaction system. Each load level was held constant for 10 minutes.

The loads were produced by a hydraulic jack and determined by a separate load cell placed on the jack. The loading test strain measurements were processed as the change of strain from just before placing the first increment of load.

In building the reaction system during the late evening of July 24, the main reaction beam (weighing 187 kips) accidentally got placed to rest on the test pile (actually, on the jack and the load cell). In the morning of July 25, before the start of the test, the beam was lifted off the pile. The event is equivalent to an unplanned and undocumented first cycle of applied load.

5. Results of a Previous Static Loading Test at the Site

On November 14, 2014, a 54 ft long test pile was installed at a distance of about 20 ft from the subject test pile. The 54-ft pile was constructed similarly to the subject test pile using a drilled and pushed casing, this time a 5.5-inch diameter with a 0.415-inch wall. After drilling the casing to full depth (54 ft) and withdrawing the casing while concreting, the casing was left a32 ft depth, leaving the lower 22-ft pile length bonded to the soil. A 3-inch diameter, threaded bar was placed in the casing to 32 ft depth. Three sister-bar strain-gages, SG1, SG2, and SG3, were installed at depths of 33, 43, and 53 ft, respectively.

A tension test was performed on the pile on November 19, 2014, to a maximum load of 240 kips. The loading schedule consisted of a series of ten 30- kip increment applied every 30-minute with a 65-minute load-holding at the tenth load, followed by ten 15-kip increments to the maximum load of 240 kips, which was held for 90 minutes. Figure 4 shows the measured pile head load-movement for the tension test.

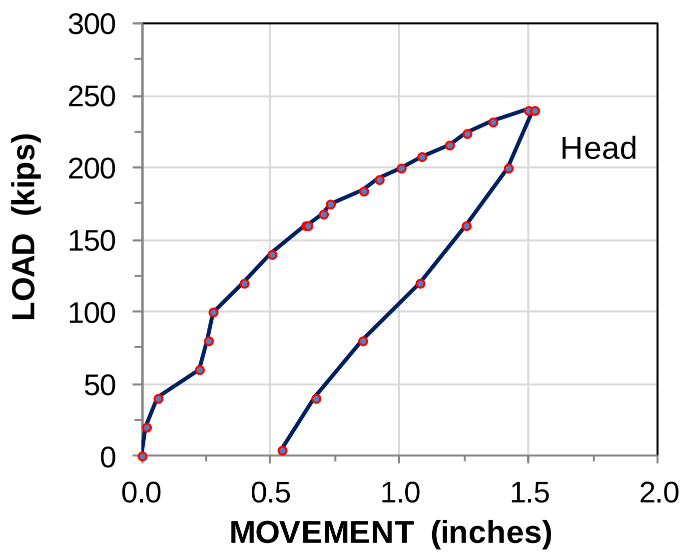

Figure 4. Pile-head load-movement of the tension test on the 54-ft pile

The load vs. strain and incremental stiffness (tangent modulus) vs. strain results of SG1 are shown in Figure 5 indicating an axial pile stiffness, EA, of 1,100 kips, which, assuming a cross section equal to the nominal 5.5 inch diameter, correlates to a 4,600 ksi Young's modulus. The SG1 strain-gage records are somewhat inconsistent. The 1,100-kip EA applied to the strain measured at Gage 1, corresponds to a load of 143 kips at the 240-kip maximum applied load, i.e., an about 100-kip shaft resistance along the upper 33-ft length and a 140-kip resistance along the lower 21-ft length of the pile.

Gage SG2 showed erratic records that proved to be not useful. Gage SG1 showed very small strain and load response commensurate with the nearness to the pile toe and indicating the absence of residual compression load in the pile.

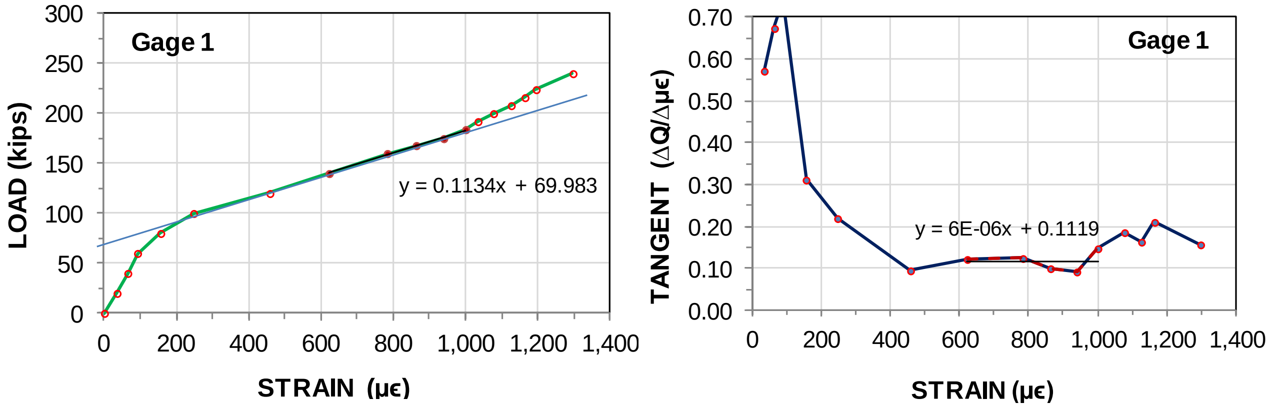

Figure 5. Load-strain and incremental stiffness (tangent-modulus) for Gage 1

6. Results of the Static Loading Test on the Subject Test Pile

Figure 6 shows the pile-head load-movement curves and the pile-head load vs. the movement of the telltale tips at 35.8 and 38.3 ft.

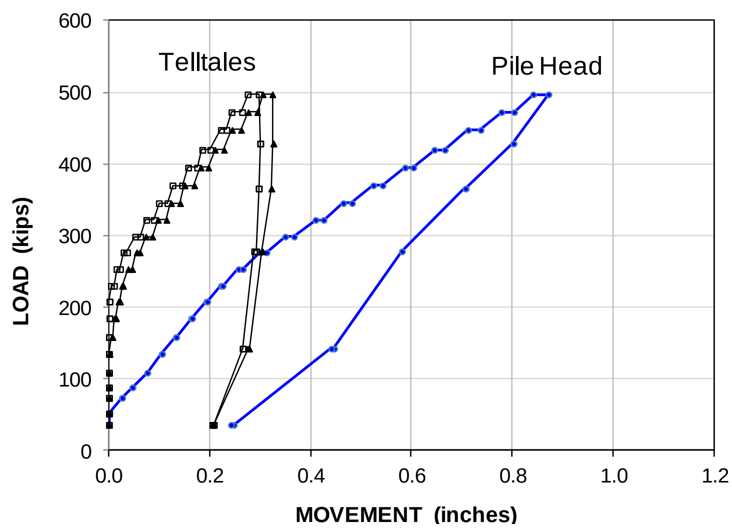

Figure 6. Load-movements measured for the EBI pile

Figure 7 shows the load vs. strain of strain-gage SG1, indicating a pile axial stiffness, EA, of 4,400 kips for the 38.7 in^2 nominal total cross sectional area of the pile.

The 4 ft below the pile head position of strain-gage SG1 makes it possible to determine the pile stiffness using the secant method as shown in Figure 7. However, as indicated by the initial steep sloping curve, the loading and unloading due to the inadvertent placing of the main beam on the pile has affected the strain-gage pile response. Most of this effect can be removed by adding 65 µε to the strain measured for each applied load. This results in an apparent pile axial stiffness to 4,400 kips.

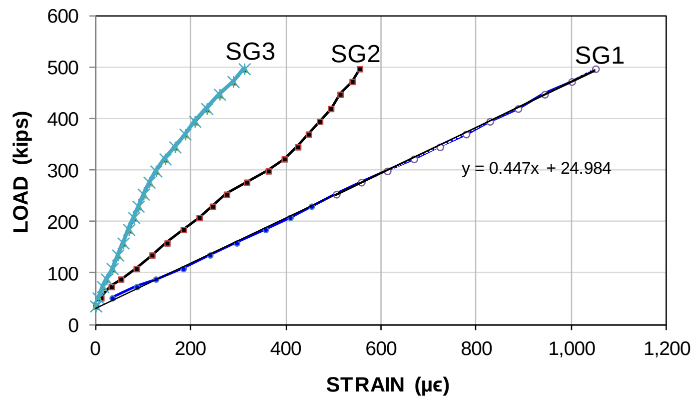

Figure 7. Load versus strain for Gage SG1

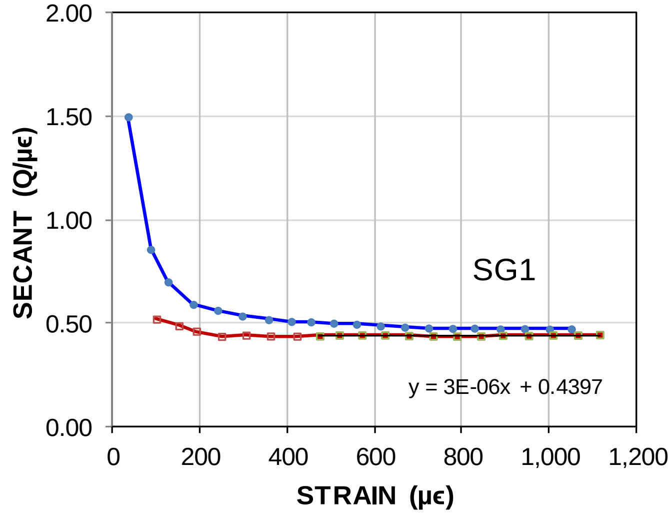

Figure 7. Secant stiffness for the Gage SG1

The alternative method to use is the incremental stiffness (tangent) as shown in Figure 8 and the stiffness indicated for SG1 is again 4,400 kips. Adjusting for 11.6 in^2 total steel area, the concrete modulus is about 4,000 ksi, which is representative for the confined conditions of the concrete inside the casing. (Applying a Poisson ratio 0.3, gives a Young's modulus of 2,900 ksi).

This method also applies to strain-gage positions further down the pile. However, Strain-gage SG2 gave erratic values and the records are considered unreliable. The strain-gage records were probably affected by the construction procedure (sloshing when the tremie pipe was emptied of water and when the casing was lifted of the EBI).

Strain-gage SG3 may be providing correct values of strain inside the EBI, but the conditions are certainly not representative for plane strain and the strain values have little analytical value.

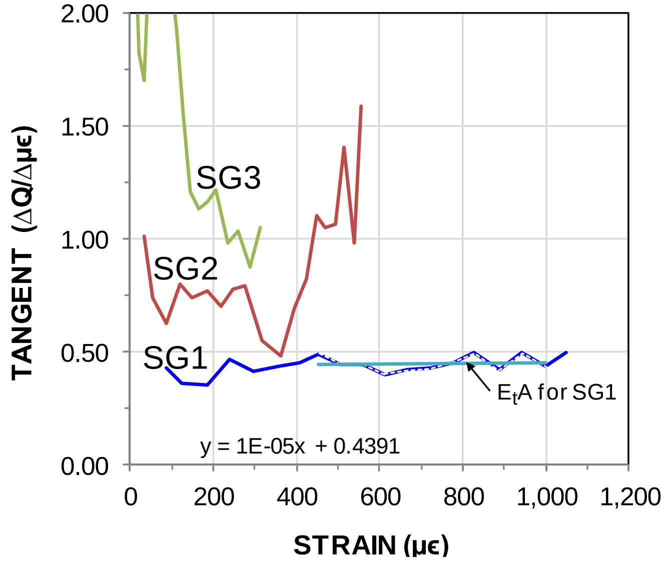

Figure 8. Incremental (tangent) stiffness for the strain-gages

6. Analysis of the Records
6.1 Tension Test Pile

In general and, in particular, for piles in sand, the evaluation of pile response to load must be made applying effective stress analysis. The 240-kip maximum load of the54 ft long tension test pile and the 143-kip load determined from SG1 at 33 ft depth results in back-calculated beta-coefficients of 1.00 for the upper length and 1.2 for the lower. The load distribution is shown in Figure 9.

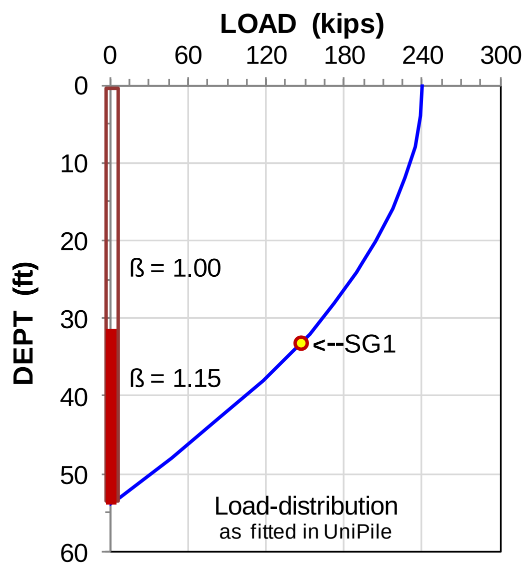

Figure 9. Load distribution at maximum applied load in the tension test

A simulation of the response was prepared using the UniPile software, applying t-z curves adjusted to make the calculated pile head movements fit the measured. The final fit was obtained by input of the same hyperbolic t-z function for the entire pile length performed using 2-ft pile elements and a assuming 100 % mobilization of the input beta-coefficient for an element movement of 0.2 inch. The measured and simulated load-movement curves are shown in Figure 10. The UniPile calculations show an 1.00-inch pile compression,, which means that the pile toe upward movement in the test was about 0.5 inch.

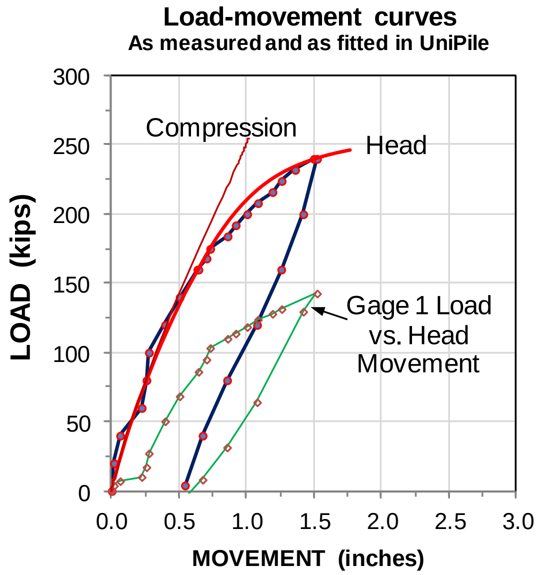

Figure 10. Load-movement curves as measured and as fitted in a UniPile simulation

6.2 The Subject 40-ft Test Pile

A similar effective stress analysis was performed on the results of the subject test using the same soil and shaft input as used in the fit to the tension test measurements with fitting the resistance at the top of the EBI so that same maximum load as applied in the test was obtained. The load-distribution calculated by UniPile is shown in Figure 11.

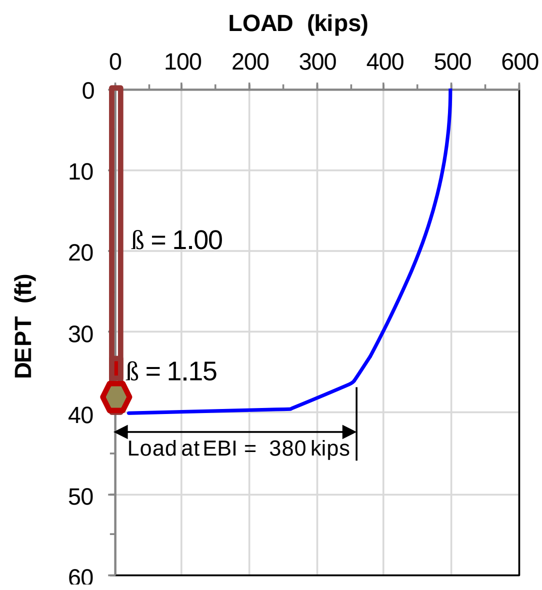

Figure 11. Load distribution at maximum applied load in the subject loading test

Keeping the same t-z functions and beta-coefficients as used for the fit of the tension test, the next UniPile analysis was made to fit the analysis also to the measured load-movement records, as shown in Figure 12. Note that not only is a good fit obtained for all of the pile head load-movement curve, the analysis also fits the telltale-measured movement above the EBI. This means that the curve marked "EBI" can be considered an accurate fit to the load at the top of the EBI for the actual 0.3-inch movement.

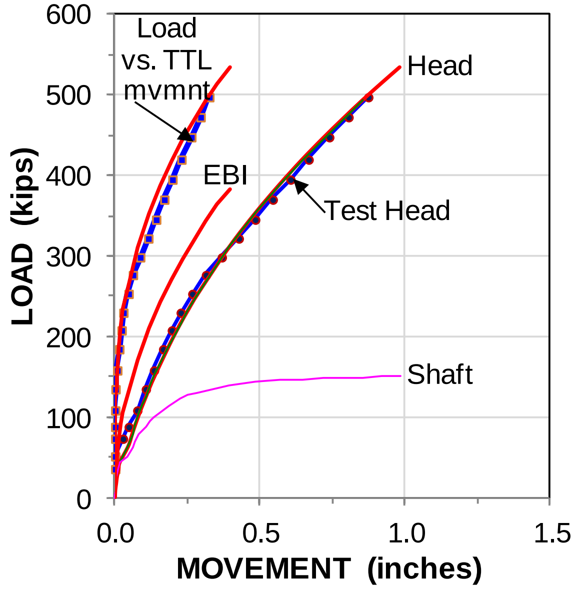

Figure 12. Subject test: Load-movement curves as measured and as fitted in a UniPile simulation

7. Conclusions

The static loading test on the EBI-equipped 7.0-inch casing showed that about 380 kips reached the EBI and generated a 0.3-inch movement. No failure, not even an incipient failure is indicated by the records.

The analysis of the distribution of shaft resistance along the tension pile and the compression pile agreed well and the same beta-coefficient and the same t-z functions were used to fit the simulated test results to the measured for the two test.

The strain-gage records of SG1 at 4 ft depth in the subject test pile gave reasonable values and indicated a concrete modulus commensurate with expected values.

The strain-gage records of SG2 in the subject test pile were probably affected by the construction procedure (sloshing when the tremie pipe was emptied of water and when the casing was lifted off the EBI).

Were additional tests considered, the comparison should be made between one pile with an EBI at the pile toe and one straight pile with no EBI. Strain-gage levels would be more useful if placed a bit further up from the EBI. It would definitely be desired to perform the test using a data logger that can take in all records, i.e., also the pile head and telltale movements ("dial-gage readings") and the load-cell values. It is also necessary to use an automatic load-holding device.

Sincerely yours.,

Bengt H. Fellenius