H4 Test Beam Table for EE ECAL End Cap Dee4 use

John Hill, RAL, March 2007

It is planned to use the existing ECAL EB Super Module table based at the H4 facility (Prevessin, Fr) for Dee4 test beam work during May/June 2007. No existing documentation has been supplied or found stating the parameters or capabilities of the H4 test beam structure nonetheless a request has been made to provide evidence regarding the safe handling of the Dee4 assembly on this table. As FE analysis would require further technical effort the decision was made to calculate the main loads using first principle hand calculations.

The H4 test beam table is mainly a welded structural hollow section assembly with two main pivot points. The whole structure can axially rotate about one and the main table can be raised or lowered via another with the use of motor-controlled ball screw threads (Fig 1).

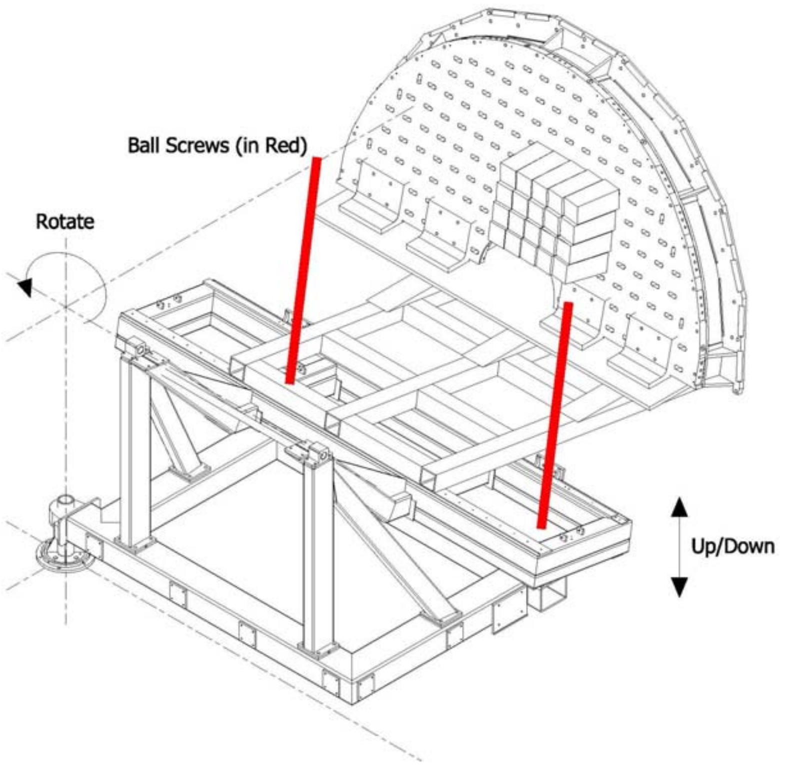

Fig 1.

a.) Calculations of Ball screw loads

Some generous assumptions have to be made with regards to the weight of structures and dimensions stated in the following calculations are approximate. The permissible axial loads for the ball screw threads have been retrieved from the THK data sheets. The thread used in this case is 55mm diameter.

Approximate mass of H4 table

It is known that the table is 4 metres x 0.9 metres (Fig 2), I have assumed that the table is steel RHS 250mm x 150mm x 10mm wall. From this it is possible to calculate the area, volume and mass of the table.

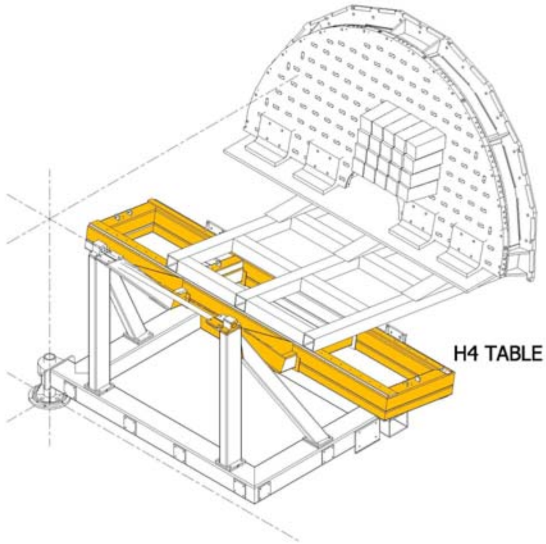

Fig 2.

$$Area = (0.25 \times 0.15) - (0.23 - 0.13)$$
$$Area = 0.0076m^2$$

$$Volume = (0.0076 \times 4 \times 2) + (0.0076 \times 0.9 \times 4)$$
$$Volume = 0.089m^3$$

Mass Density of steel = 7810 kg/m^3
Table mass is therefore $= 7810 \times 0.089 = 688kg$

With the remaining link arms and fixtures a conservative estimate of the H4 table mass can be made at 1000kg.

Approximate mass of Dee4 and Support Table

The basic structure has been designed and detailed at CERN (Fig 3). At the moment of writing the decision on sectional hollow section thickness has not been made however based on the information supplied we can again make a conservative estimate of the table mass at 1000kg**.** Deflection and stress calculations of the table are made in section b.) of this report.

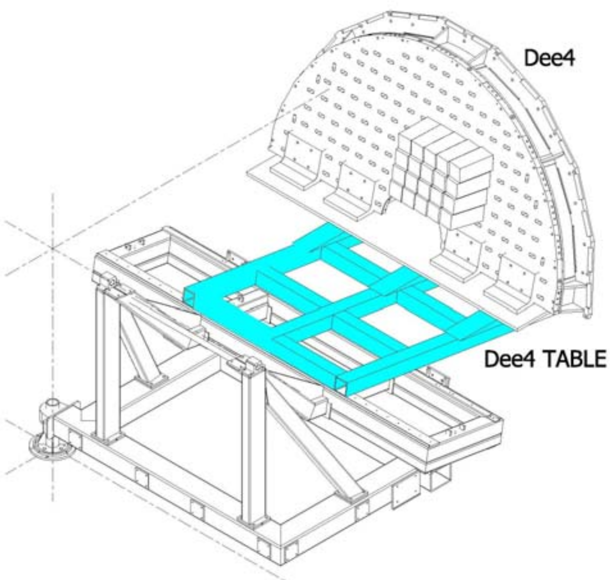

Fig 3.

The weight of Dee4 has been specified as 2000kg**,** the location and arrangement of this assembly can also be seen on Fig 3.

Reaction forces on Ball Screw Threads

From the information specified we are now able to calculate the tensile/compressive load on the existing THK Ball Screw Thread of the H4 structure.
We can calculate the load at *Fs* using basic principles with the information supplied in Fig 4.

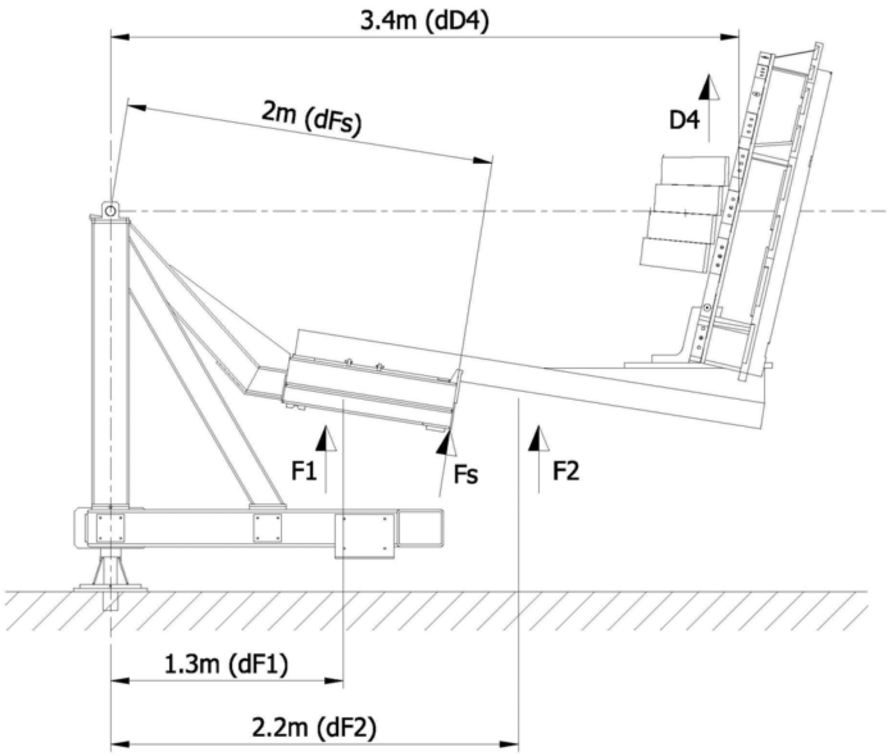

Fig 4.

Where *F1 = force of H4 table*
F2 = force of Dee4 table
D4 = force of Dee 4
g = gravity 10m/s (approx)

Thus $$(mF1g) \times dF1 + (mF2g) \times dF2 + (mD4g) \times dD4 = Fs \times dFs$$

With data $$(1000 \times 10) \times 1.3 + (1000 \times 10) \times 2.2 + (2000 \times 10) \times 3.4 = Fs \times 2$$

$$13000 + 22000 + 68000 = Fs \times 2$$

$$\frac{103000}{2} = Fs$$

***Fs* = 51.5 kN**

Therefore resulting compressive load screw threads is **51.5 kN** (or **26 kN** per screw thread).

Inspecting the current arrangement we can see that both ends of the thread are pinned, thus the formula for calculating the critical buckling load is:

$$P_{crit} = \frac{\prod^2 EI}{L^2}$$

Where *E = Young's Modulus of screw thread material*
I = Second moment of Inertia of screw thread section
L = length of screw thread

Young's Modulus for Stainless Steel is 210 GN/m^2
Second moment of inertia can be calculated where core diameter of thread is 49mm (0.049m)

Where $I = \frac{\Pi d^4}{64} \qquad = \frac{3.14 \times 0.049^4}{64} \qquad = 283\text{x}10^{-9}\ \text{m}^4$

Thus $P_{crit} = \frac{3.14^2 \times (210 \times 10^9) \times (283 \times 10^{-9})}{2^2} \qquad = \frac{585.9 \times 10^3}{4} \qquad = \mathbf{146.5\ kN}$

Results and conclusions

We are able to retrieve the correct data from the THK selection sheets (Fig 5). As both ends of the ball screw threads for the H4 table are able to rotate about a pinned axes, from engineering principles it is known that the resulting compressive load figure will be four times better than the 'Fixed – Free' mounting arrangement.

From Graph we can summarize that kN x 4 = Permissible Compressive load per screw
18 x 4 = **72kN** per screw thread

From calculations load Fs = **26kN** per screw thread

The result above indicates that the compressive load calculated for the H4 Test beam table with Dee4 attached is suitable for ECAL EE End Cap use. Therefore this should allow the group to proceed with the proposed scheme of attaching the Dee4 End Cap to the existing test facility.

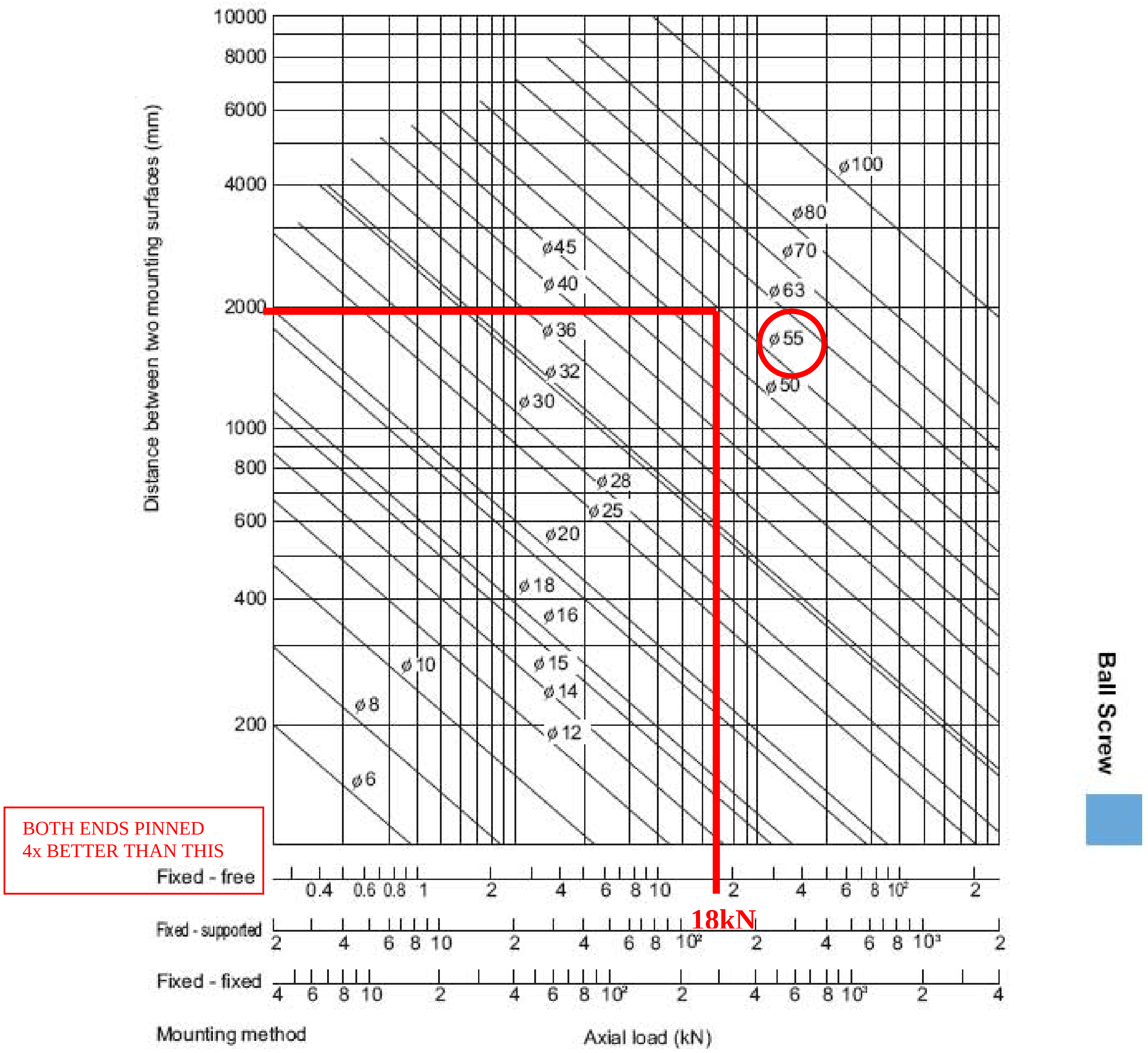

Fig.8 Permissible Tensile Compressive Load Diagram

Fig 5.

b.) Deflection and Stress calculations of Dee4 Table

The basic construction of the Dee4 table is structural hollow section 140mm x 140mm, there are two thickness's available at 8mm and 12mm. For the purposes of this exercise I will calculate the deflection and maximum stress for both 8 and 12mm sections.

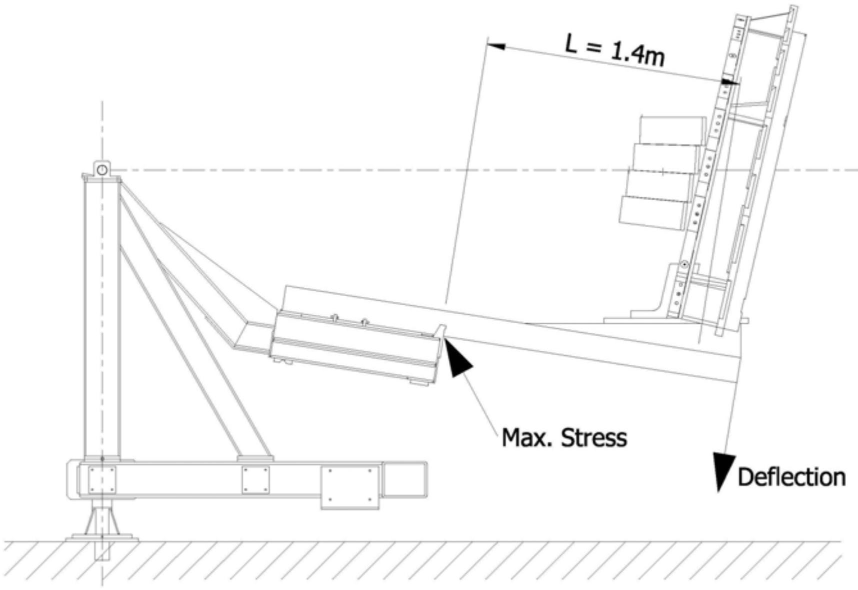

Fig 6.

Second Moment of Inertia for SHS

For 8mm thickness $I = \frac{outerD^4}{12} - \frac{innerD^4}{12} \quad = \frac{0.14^4}{12} - \frac{0.124^4}{12} \quad = 12.3\text{x}10^{-6}\ \text{m}^4$

For 12mm thickness $I = \frac{outerD^4}{12} - \frac{innerD^4}{12} \quad = \frac{0.14^4}{12} - \frac{0.116^4}{12} \quad = 17\text{x}10^{-6}\ \text{m}^4$

Resulting Load of Dee4

The current design of table has 3 transverse beams supporting Dee4

Load W = Mass x g *= 2000 x 10* = 20000 N / 3 beams = 6666 N per beam

Deflection of Beam

Where Deflection $= \frac{WL^3}{3EI}$

Further data required *E = Young's Modulus of SHS beam material* 200 GN/m^2
I = Second moment of Inertia of SHS beam (8 or 12mm)
L = distance from fixed end to load W (refer to Fig 6).

For 8mm thick section $= \dfrac{6666 \times (1.4)^3}{3 \times (200 \times 10^9) \times (12.3 \times 10^{-6})}$ = 0.00248 m or **2.48 mm**

For 12mm thick section $= \dfrac{6666 \times (1.4)^3}{3 \times (200 \times 10^9) \times (12.3 \times 10^{-6})}$ = 0.00179 m or **1.79 mm**

<u>Maximum Stress of Beam</u>

Where Stress $\delta = \dfrac{My}{I}$

Bending Moment M = WL *M = 6666 x 1.4* = 9.4 kNm

Distance y = L/2 *y = 1.4 m/2* = 0.07m

For 8mm thick section $\delta = \dfrac{9400 \times 0.07}{12.3 \times 10^{-6}}$ = **53.5 MN/m^2**

For 12mm thick section $\delta = \dfrac{9400 \times 0.07}{17 \times 10^{-6}}$ = **38.7 MN/m^2**