CUSTOMER SUPPORT NOTE

Smooth Contact Joints

Note Number:	**CSN/LUSAS/1009**

This support note is issued as a guideline only.

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Rev: 18-Jul-03

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1. Introduction

This Technical Note is intended to clarify the following help entries and to give some practical guidance for the use of **Smooth Contact** joints.

Help topics > Theory manual > Chapter 4 Constitutive models > 4.11 Joint Models

Help topics > Modeller user manual > Building a model > Attributes > Material properties > Joint material properties

2. Force/displacement graphs and terminology

The help menu entries include a generalised graph of a force/ strain relationship for smooth contact joints. Although "force/strain" is technically applicable in the FE solution, since strain is understood by engineers to be [change in length/original length], it is more helpful to describe the relationship as Force/displacement (F/ d).

Essentially, the smooth contact joint allows the specification of a spring with different stiffnesses in compression ("contact", Kc) and tension ("lift-off", K1).

Initial gap (g)
This specifies the displacement at which the change in stiffness (Kc to K1) occurs.

- If g=0, stiffness changes around zero displacement i.e. positive (K1), negative (Kc)
- If g=non zero, stiffness changes around displacement = -g.

Lift-off force (Fy)
This specifies the force at which the change in stiffness (Kc to K1) occurs.

- If Fy=0, stiffness changes between tension (K1) and compression (Kc)
- If Fy=non zero, stiffness changes at the specified "tension level"

At the start of the analysis, the joint element is assumed to have <u>zero force</u>.
- If g=0 and Fy=0, then there is zero strain at zero force.
- If g=non zero, there is strain at zero force = "initial lack of fit": d=-g
- If Fy=non zero, there is strain at zero force = "initial lack of fit": d=-Fy/Kc
- If g=non zero and Fy=non zero, there is strain at zero force = "initial lack of fit": d=-(Fy/Kc+g)

Therefore equations 4.8-9 to 4.8-11 may be recast as follows:

[4.11-10] Where force in the joint, F < Fy. current displacement, d = -(Fy/Kc+g)+F/Kc
[4.11-11] At F=Fy, yield occurs. Displacement at yield, d = -g
[4.11-12] Where force in the joint, F > Fy. current displacement, d = (F – Fy)/K1 - g

This may be illustrated as follows:

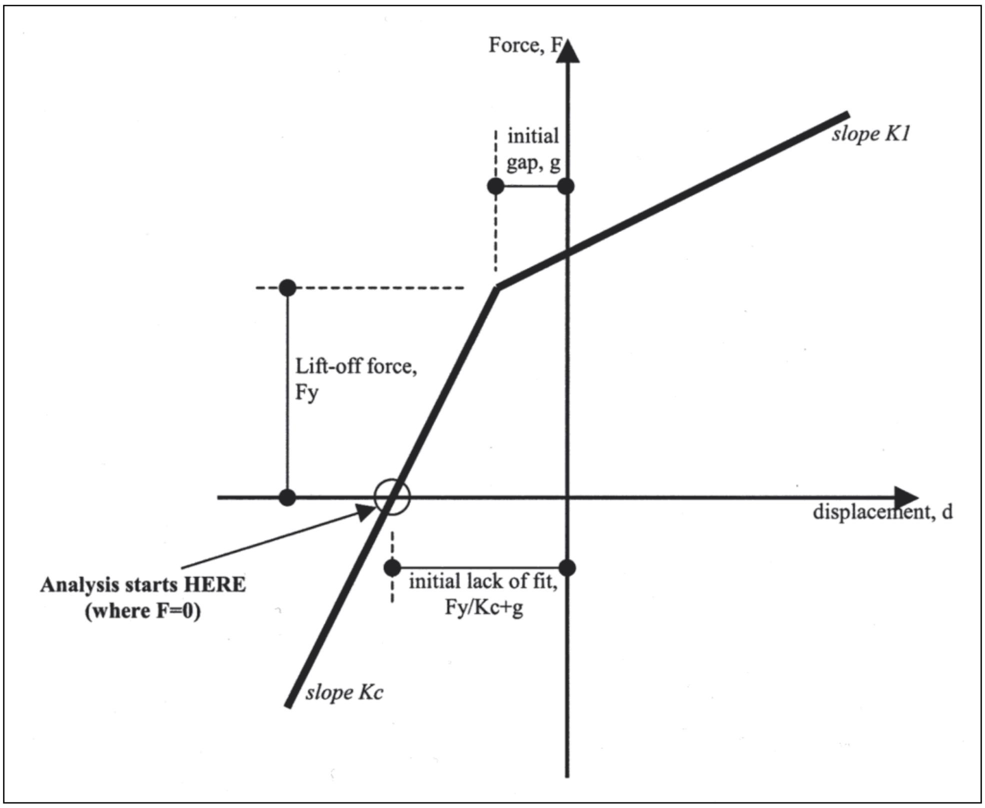

Figure 1: Force/displacement graph for the Smooth Contact Joint

Using some example figures, let us suppose that Kc = 2, K1 = 0.5, g = 2, Fy = 6

At F = 0, F < Fy. Displacement at start of analysis, d0 = -(6/2+2) = -5
At F = 6, F = Fy. Displacement at yield, dy = -2
At F = 10, F > Fy. Displacement, d = (10 – 6)/0.5 – 2 = 6

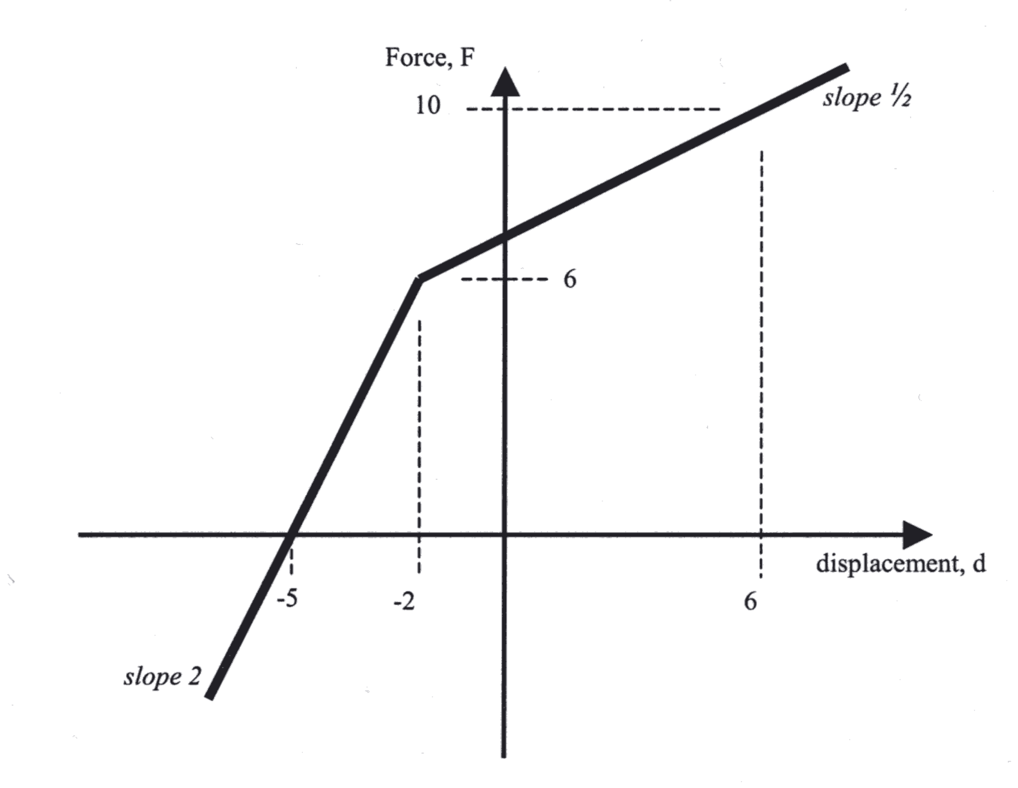

Figure 2: Example Force/displacement graph for a Smooth Contact Joint

3. Examples of using Smooth Contact Joints

Uses of smooth contact joints which illustrate the different features include:

- ❖ A cantilever with a compression-only prop
- ❖ Compression-only supports for a 2D frame structure
- ❖ Tension-only members in a 3D model
- ❖ Nonlinear (yielding) springs
- ❖ Oversize spring introduced as a temporary support
- ❖ Sunken supports in a beam model

Note that the orientation of the joint mesh elements is crucial. Therefore it is prudent always to use a local coordinate dataset to control the axes in mesh elements. This dataset must be defined before the mesh attribute is assigned; assigning it later will NOT reorientate the element. A local coordinate system may be defined using the menu item:

Attributes > Local coordinate…

More information on local coordinates may be found in the help menu item:

Help Topics > Modeller User Manual > Building a model > Attributes > Local coordinate systems

The mesh attribute may now be assigned in the normal way; select the appropriate line features with the mouse and then drag the mesh attribute from the Treeview to the graphics screen. When the mesh attribute is assigned to the line feature a local coordinate dataset can be specified for use in the assignment (recommended).

The element axes can be checked using:

Treeview > Layers tab > Mesh > (tick) Show Element Axes

3.1 Cantilever with a compression only prop

Suppose we should wish to model the system illustrated below where the right-hand sprung support is only effective in compression.

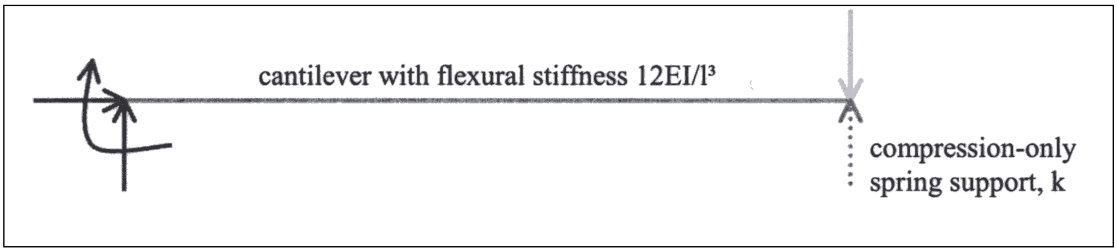

Figure 3: Cantilever with a sprung prop support

Where the sprung support is only effective in compression and the displacement at the load position is the only quantity of interest. The WHOLE SYSTEM can be modelled as a single smooth contact joint element. The Y-direction force/displacement graph is:

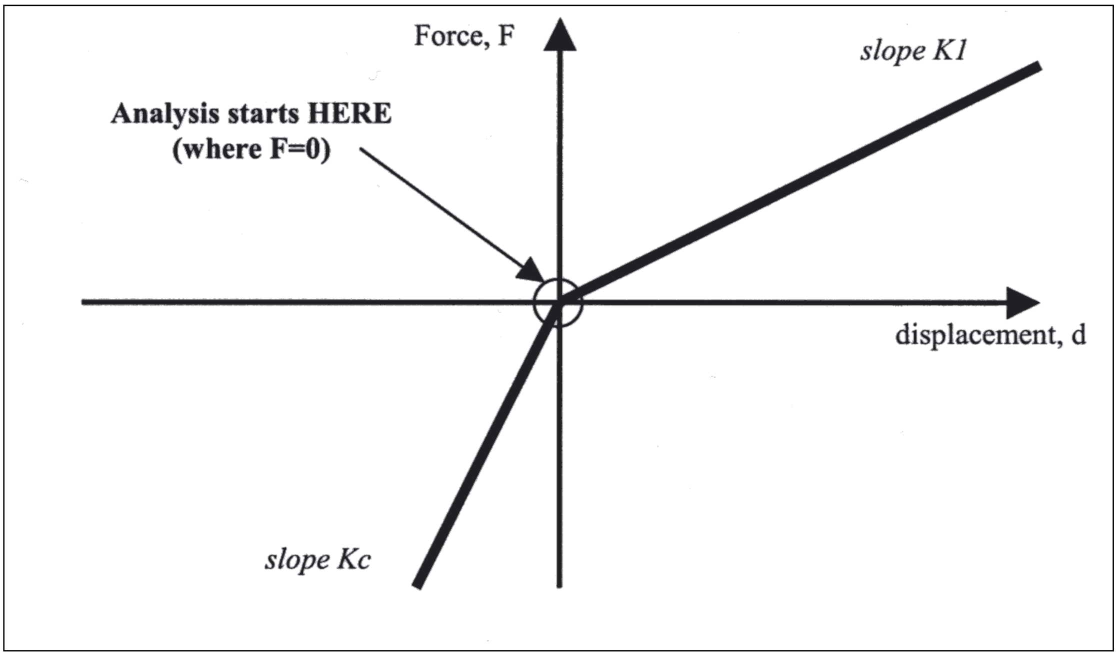

Figure 4: Force/displacement graph for a cantilever with a sprung compression-only prop

The joint material attribute may be defined using the menu item:

Attributes > Material > Joint > (drop-down lists) Joint type=Smooth contact, Freedoms=3

A table of 5 rows must be completed.

Row 1: “Contact spring stiffness” (Kc). A suitable value should be entered for the 3 DOF (in order local x, y, THz), based on the stiffness of the cantilever ($12EI/l^3$) plus the spring support (k).
Row 2: “Mass” may be left blank unless a dynamic analysis is being undertaken where a lumped mass is required.
Row 3: “Lift-off force” at which the joint stiffness changes from Kc to K1; in this case Fy=0
Row 4: “Lift-off stiffness” (K1). A suitable value should be entered for the 3 DOF (in order local x, y, THz), based on the stiffness of the cantilever alone (classically $12EI/l^3$). K1 < Kc in this example.
Row 5: “Initial gap” (g) is zero for this application.

Alternatively the system might be modelled with the cantilever as beams and a smooth contact joint modelling the spring stiffness of a *compression only support* as illustrated below. For this case, Kc=k, K1=0. Note that the joint has been given a length in this illustration for clarity but should have no length in the stiffness matrix. Any length given will trigger a warning in the LUSAS Solver text output file (filename.out).

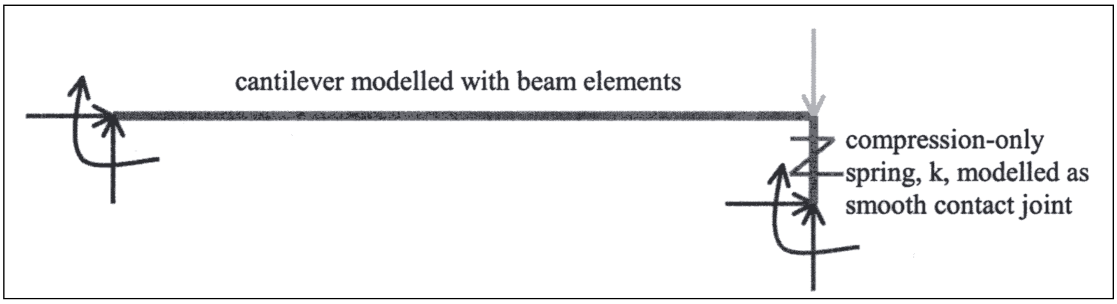

Figure 5: Cantilever as a beam with a sprung compression-only prop as a joint

3.2 Compression-only supports for a 2D frame structure

A joint element may be placed between coincident nodes where lift-off is required. In Figure 5 above, a compression-only joint is placed between the end of the cantilever and a fixed support node.

The joint material attribute may be defined using the menu item:

Attributes > Material > Joint > (drop-down lists) Joint type=Smooth contact, Freedoms=3

A table of 5 rows must be completed.

Row 1: “Contact spring stiffness” (Kc). A suitable value should be entered for the 3 DOF (in order local x, y, THz), based on the required stiffness for the spring support (k).
Row 2: “Mass” may be left blank unless a dynamic analysis is being undertaken where a lumped mass is required.
Row 3: “Lift-off force” at which the joint stiffness changes from Kc to K1; in this case Fy=0
Row 4: “Lift-off stiffness” (K1). A suitably un-stiff value (near zero) should be entered for the 3 DOF (in order local x, y, THz).
Row 5: “Initial gap” (g) is zero for this application.

3.3 Tension-only members in a 3D model

The joint material attribute may be defined using the menu item:

Attributes > Material > Joint > (drop-down lists) Joint type=Smooth contact, Freedoms=6

A table of 5 rows must be completed.

Row 1: "Contact spring stiffness" (Kc). A suitably un-stiff value (near zero) should be entered for the 6 DOF (in order local x, y, z, THx, Thy, THz).
Row 2: "Mass" may be left blank unless a dynamic analysis is being undertaken where a lumped mass is required.
Row 3: "Lift-off force" at which the joint stiffness changes from Kc to K1; in this case Fy=0
Row 4: "Lift-off stiffness" (K1). A suitably stiff value should be entered for the 6 DOF (in order local x, y, z, THx, Thy, THz).
Row 5: "Initial gap" (g) is zero for this application.

The force/displacement graph for this application, with Kc=0, Fy=0 and g=0 would be:

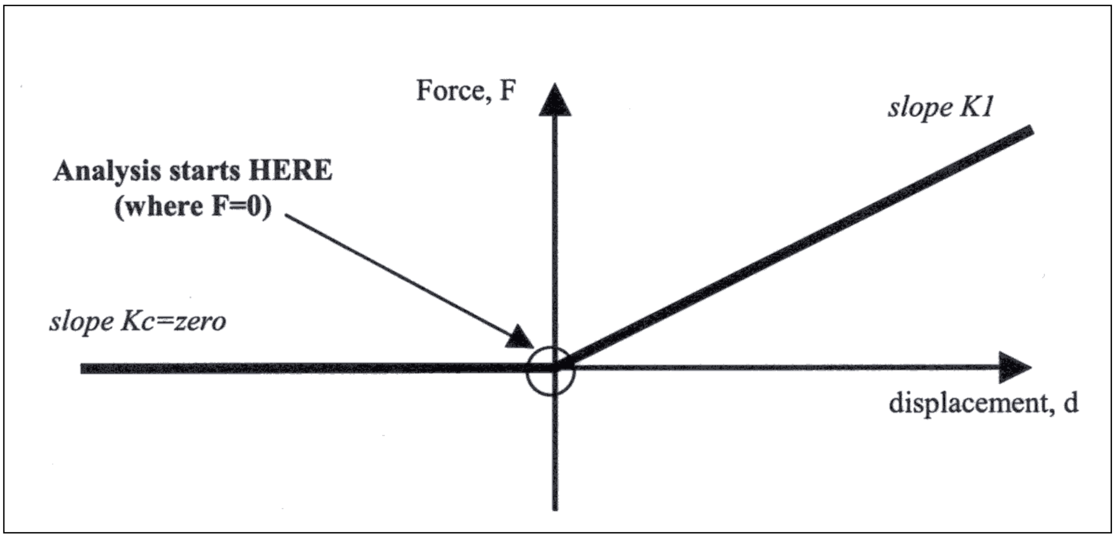

Figure 6: Force/displacement graph for a joint modelling a tension-only member

3.4 Nonlinear (yielding) spring

In the instance where a spring exists in a structure but may change stiffness due to (for example) material yielding, an appropriate non-zero Fy value should be entered in the joint material attribute, together with an appropriate "initial gap". The force/displacement graph for such a spring is illustrated in Figure 7.

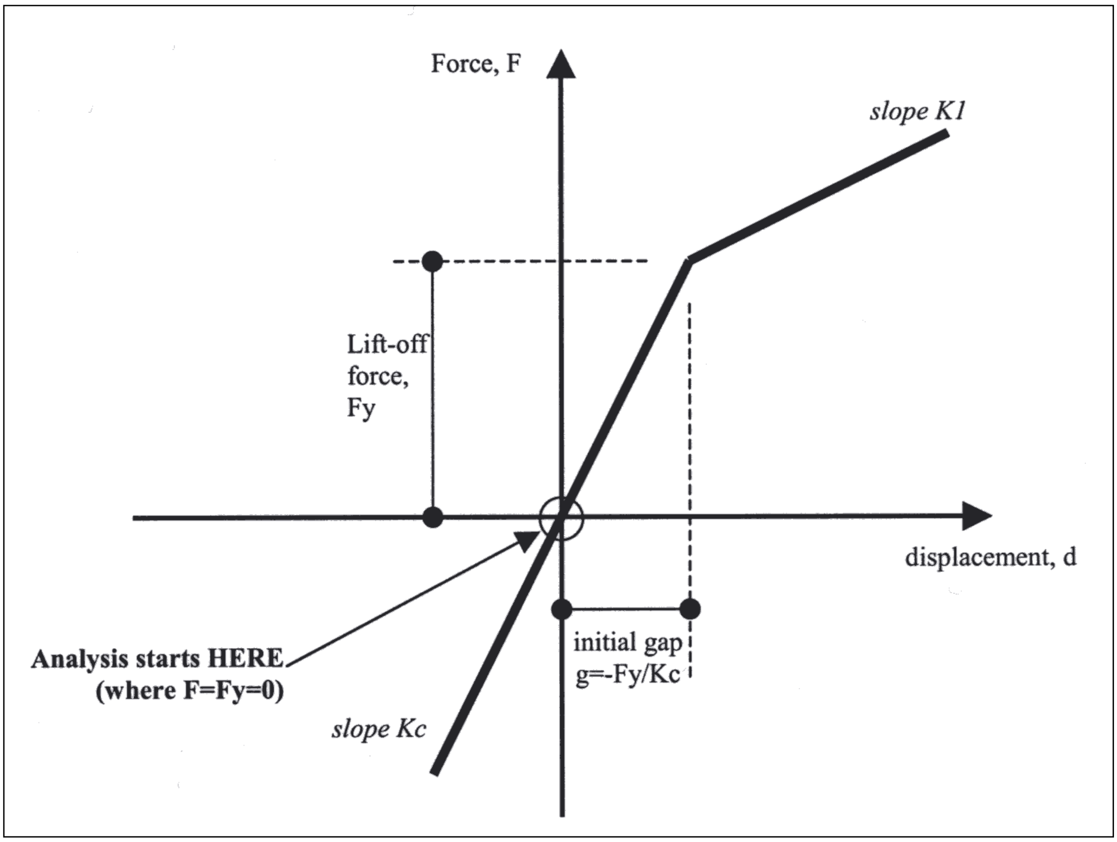

Figure 7: Force/displacement graph for a joint modelling a nonlinear (yielding) spring

3.5 Oversize spring introduced as a temporary support

Suppose we should wish to model the system illustrated below – an oversize spring is introduced at mid-span in the fixed ended beam.

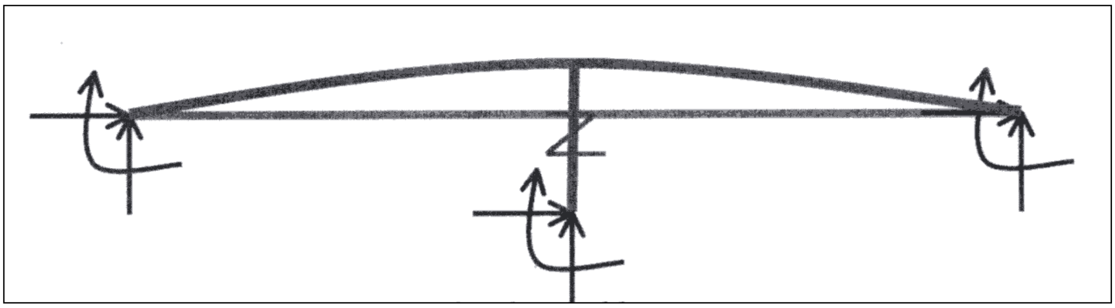

Figure 8: Oversize spring at mid-span in a fixed ended beam

The (expected) equilibrium state is illustrated – a deformation of magnitude < “initial lack of fit”. There is a force in the spring. If the beam was perfectly rigid (or a rigid support), there would be a compressive force in the spring F = Kc x g. If the beam was perfectly flexible (or not present) there would be no force in the spring and a deflection of g.

The full force/displacement graph is illustrated in Figure 9.

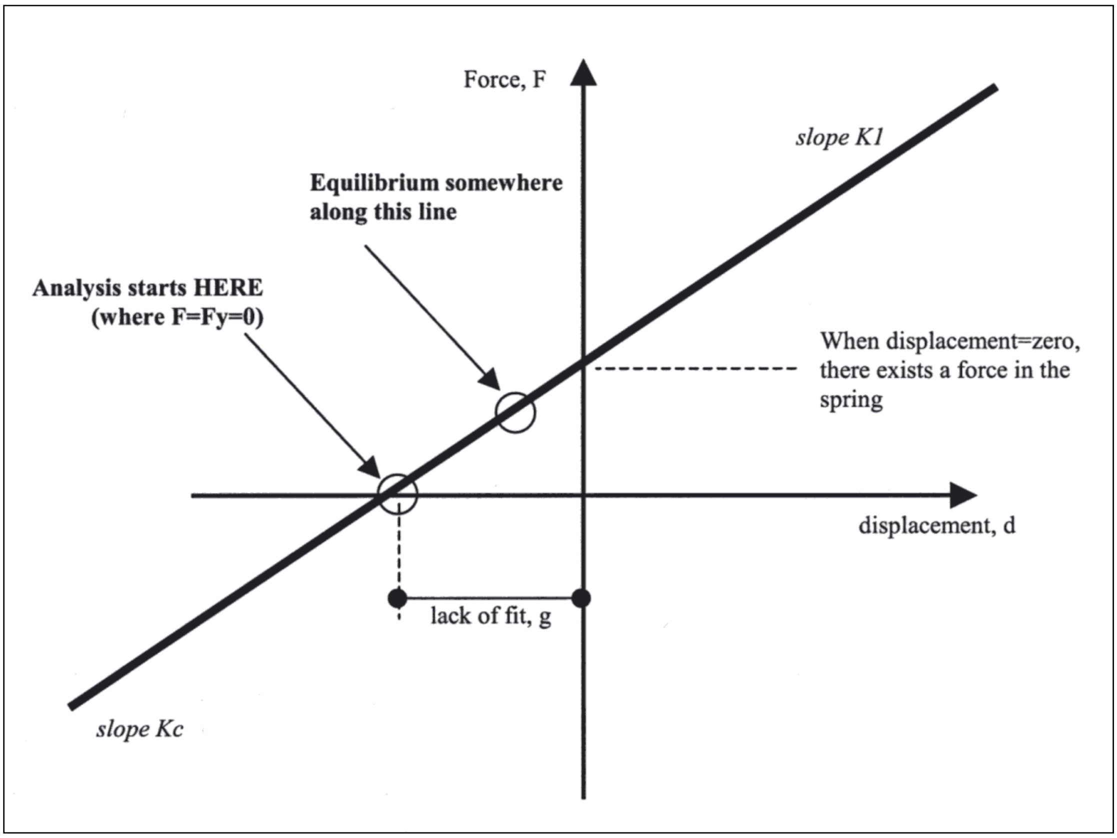

Figure 9: Force/displacement graph for a joint modelling an oversize spring

3.6 Sunken supports in a beam model

A cantilever similar to that illustrated in the Theory Manual article referenced may be modelled using beam elements and a joint element with an "initial gap" (g).

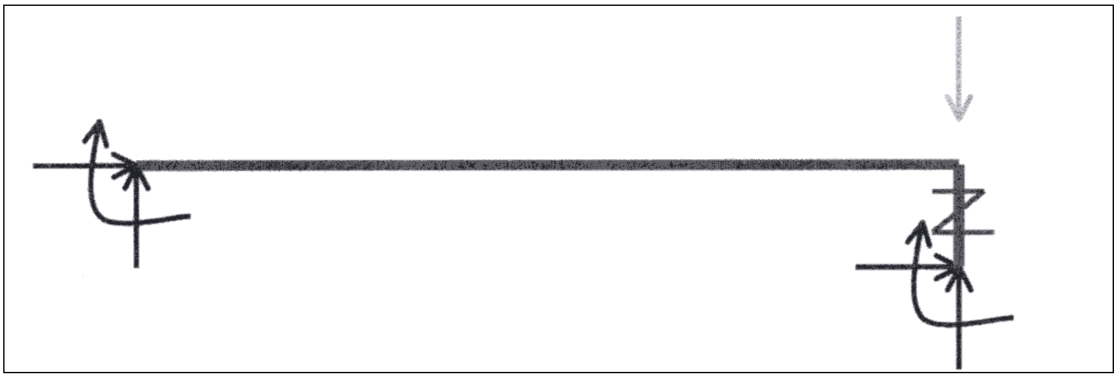

Figure 10: Cantilever with sunken support

The joint material attribute may be defined using the menu item:

Attributes > Material > Joint > (drop-down lists) Joint type=smooth contact

A table of 5 rows must be completed.

Row 1: "Contact spring stiffness" (Kc). A suitably stiff value should be entered.
Row 2: "Mass" may be left blank unless a dynamic analysis is being undertaken where a lumped mass is required.

Row 3: "Lift-off force" at which the joint stiffness changes from Kc to K1; in this case Fy=0
Row 4: "Lift-off stiffness" (K1). A suitably un-stiff value (near zero) should be entered.
Row 5: "Initial gap" (g). A suitable non-zero value should be entered.

The force/displacement graph for this application, with K1=0 and Fy=0 would be:

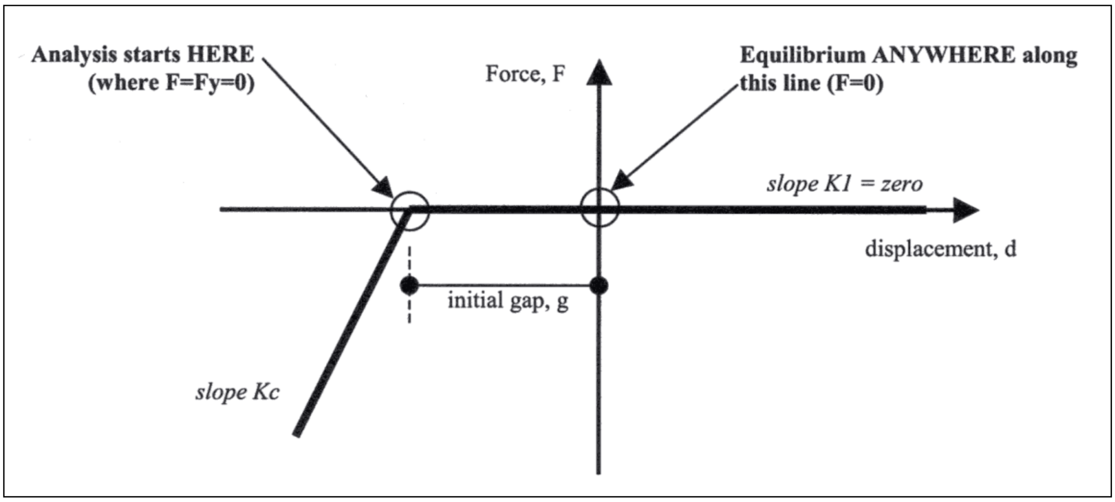

Figure 11: Force/displacement graph for a joint modelling a sunken support.

Although "the joint element is initially assumed to be in a contact state", the lift-off stiffness (K1) is zero. Therefore it requires zero force to open the required gap.

4. References

LUSAS Modeller User Manual.

LUSAS Theory Manual 1.