

CBUSH & CELAS RESULTS INTERPRETATION

1. INTRODUCTION

The scope of this document is to explain how the results of CELAS and CBUSH elements must be interpreted.

In the first chapter, some generic aspects of both elements are going to be discussed.

In the second chapter different variations of the uses of both elements are going to be explained by means of an example. At the same time that the examples are displayed, the possible mistakes for each one of them will be explained.

Finally, in the last chapter the main conclusions of the previous analyses will be listed.

2. THEORETICAL BEHAVIOUR OF CELAS & CBUSH

- CELAS

The CELAS1 element represents a scalar spring which can join two DOF or ground a DOF. Although it is possible to use the CELAS2 elements instead of CELAS1, only the CELAS1 is going to be used in this document, but the results are valid for both of them since the only difference is the properties definition.

An example of a CELAS1 and PELAS card is displayed below.

```

CELAS1 11 2 5 1 14 1
...
PELAS 2 100000.
  
```

For the previous example, the CELAS1 element joins the DOF 1 of nodes 5 and 14. The properties of the CELAS1 are defined in the PELAS card which defines the value of the stiffness of the scalar spring (100000).

Note that the DOF of the nodes are referenced to the corresponding node analysis coordinate system.

The force of this element are computed using the following equation:

$$F = k(u_A - u_B)$$

Where:

k : Stiffness of the scalar spring.

u_A : DOF of the first grid.

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u_B : DOF of the second grid.

For the previous example, the equation will result in the following expression:

$$F = 100000(u_5 - u_{14})$$

It is important to notice that the CELAS elements should be used only when both nodes are coincident because otherwise spurious forces could be generated.

- CBUSH

The CBUSH element represents a spring as well as the CELAS does, but with some differences.

For this element the spring location is always considered placed at a specific position (Length multiplied by 'S' from node A) between the two nodes which is set by means of the 'S' value. All the stiffness components can be set with one element, so to model a fastener, only one element is necessary. The spring location is internally connected by NASTRAN with two internal nodes as if there were RBE2 (123456) between the spring and the nodes A and B as shown in the following figure:

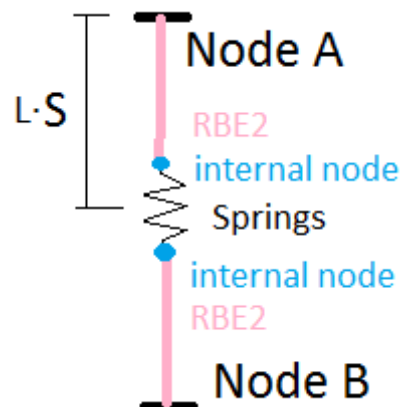


Figure 1: NASTRAN internal simulation of a CBUSH

In this case, the stiffness directions are referenced to the element coordinate system which can be defined by means of the orientation vector (if the element length is not null) or by a coordinate system. This element coordinate system is used internally as the analysis coordinate system of the internal nodes. The springs are internally CELAS elements between coincident internal nodes.

If the springs used are only translational, the connection at this location is a spherical hinge. If $S=0$ then the hinge is located at node A and a clamp is simulated at node B. If $S=1$ then the hinge is located at node B and a clamp is simulated at node A.

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As a consequence of the previous aspects the CBUSH element is more straightforward for modelling fasteners.

The NASTRAN code for the CBUSH element is shown below:

```
CBUSH 11 2 5 14 1. 0. 0.
...
PBUSH 2 K 10000. 10000. 10000. 10000. 10000. 10000.
```

```
CBUSH 11 2 5 14 1
...
PBUSH 2 K 10000. 10000. 10000. 10000. 10000. 10000.
```

In the previous code the CBUSH element joints the nodes 5 and 14. For the first code, the element coordinate system is defined by means of the x axis (from node 5 to node 14) and the orientation vector which defines the plane 1.

In the second case, the element coordinate system is defined by means of the coordinate system (coordinate system 1 for the example).

3. EXAMPLE & POSSIBLE MISTAKES

The best way to understand how the CELAS and CBUSH elements work is with an example. The example which is shown below, consist of 8 CQUAD4 and one 1D element which connect some of them. The upper plate is loaded with a z load, and the lower plate is clamped.

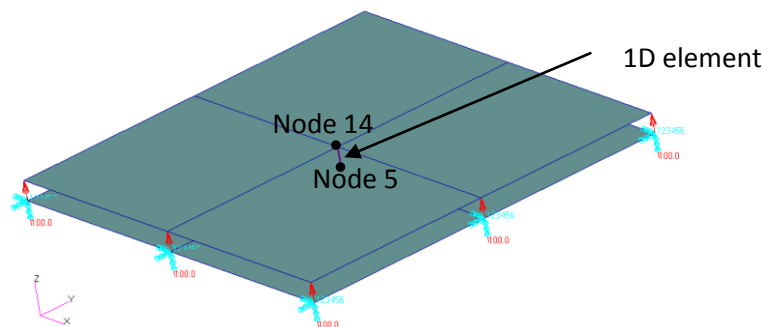


Figure 2: Example

The upper plate is loaded with 100N on each of its boundary nodes, so the fastener must transfer 800N to the lower plate. Consequently, the fastener will work under tension load which is normally represented as a positive force in the element.

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- CBUSH case
 - Length≠0 and orientation vector

For this case, it is possible to use the orientation vector since the length of the element is not null. As a consequence the x axis is in the element direction (from node GA to GB) and the other axes are defined by means of the orientation vector.

The NASTRAN code of this example is plotted below:

```

SOL 101
CEND
ECHO = NONE
SUBCASE 1
  SPC = 2
  LOAD = 2
BEGIN BULK
PSHELL 1 1 1. 1 1
CQUAD4 1 1 1 2 5 4
CQUAD4 2 1 2 3 6 5
CQUAD4 3 1 4 5 8 7
CQUAD4 4 1 5 6 9 8
CQUAD4 5 1 10 11 14 13
CQUAD4 6 1 11 12 15 14
CQUAD4 7 1 13 14 17 16
CQUAD4 8 1 14 15 18 17
PBUSH 2 K 100000. 100000. 100000. 100000. 100000. 100000.
CBUSH 11 2 5 14 1. 0. 0.
MAT1 1 70000. .3
GRID 1 0. 0. 0.
GRID 2 100. 0. 0.
GRID 3 200. 0. 0.
GRID 4 0. 100. 0.
GRID 5 100. 100. 0.
GRID 6 200. 100. 0.
GRID 7 0. 200. 0.
GRID 8 100. 200. 0.
GRID 9 200. 200. 0.
GRID 10 0. 0. 10.
GRID 11 100. 0. 10.
GRID 12 200. 0. 10.
GRID 13 0. 100. 10.
GRID 14 100. 100. 10.
GRID 15 200. 100. 10.
GRID 16 0. 200. 10.

```

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```

GRID 17      100. 200. 10.
GRID 18      200. 200. 10.
SPCADD 2     1
LOAD 2       1.   1.   1
SPC1 1       123456 1   2   3   4   6   7
           8   9
FORCE 1      10   0  100.  0.  0.  1.
FORCE 1      11   0  100.  0.  0.  1.
FORCE 1      12   0  100.  0.  0.  1.
FORCE 1      13   0  100.  0.  0.  1.
FORCE 1      15   0  100.  0.  0.  1.
FORCE 1      16   0  100.  0.  0.  1.
FORCE 1      17   0  100.  0.  0.  1.
FORCE 1      18   0  100.  0.  0.  1.
CORD2R 1     0   100. 100.  0.  100. 200.  0.
           100. 100. 10.
CORD2R 2     0   100. 100. 10.  100.  0.  10.
           100. 100.  0.

```

The CBUSH element connects the nodes 5 and 14 so the x axis is defined by the vector from the node 5 to the node 14. So, it will have the same direction that the z basic axis.

The NASTRAN analysis reports a positive displacement in the nodes 5 and 14 and the element force which is displayed below:

```

FORCES IN BUSH ELEMENTS      (CBUSH)
ELEMENT-ID      FORCE-X      FORCE-Y      FORCE-Z      MOMENT-X      MOMENT-Y      MOMENT-Z
11              8.000000E+02  -5.324811E-25  5.022170E-13  1.585729E-23  2.379923E-10  -5.402913E-11

```

All the previous results are the expected ones, since the displacements are positive for both nodes and the element force is positive.

With this kind of model, the x element axis is always oriented from node GA to GB and the results are always the expected ones. The bush element force is positive if there is traction and negative if there is compression. The same results in x direction would be obtained swapping nodes A and B on the CBUSH definition.

- Length≠0 and CID

For this case, the element coordinate system is input directly using a defined coordinate system in NASTRAN. The element forces are computed as $K \cdot (u_B - u_A)$.

Only the CBUSH card of the NASTRAN code is modified.

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CBUSH	11	2	14	5	1
-------	----	---	----	---	---

CBUSH	11	2	14	5	2
-------	----	---	----	---	---

Two different examples are going to be analysed, one with the coordinate system 1 as element coordinate system and another one using the coordinate system 2.

As it can be seen in the NASTRAN code of the example (displayed in the previous case), the coordinate system 1 has its x axis oriented in the z direction of the basic coordinate system. So it is like the x element when the bush element is defined with the orientation vector (from node 5 to node 14). But the coordinate system 2 has its x axis in the reverse direction (negative z) so it is like the vector which joints the node 14 with the node 5.

An sketch of the x axis is displayed below:

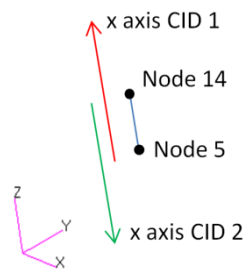


Figure 3: x axes of CID 1 and 2

After analysing both cases, the following results are obtained:

For the CID 1 analysis, the displacements are positive ($z > 0$) and the forces in the CBUSH element are as follows:

```

FORCES IN BUSH ELEMENTS      (CBUSH)
ELEMENT-ID    FORCE-X    FORCE-Y    FORCE-Z    MOMENT-X    MOMENT-Y    MOMENT-Z
      11      8.000000E+02  -5.324811E-25  5.022170E-13  1.585729E-23  2.379923E-10  -5.402913E-11
  
```

And for the CID 2 analysis, the displacements are also positive, but the forces in the CBUSH element are different from the previous ones.

```

FORCES IN BUSH ELEMENTS      (CBUSH)
ELEMENT-ID    FORCE-X    FORCE-Y    FORCE-Z    MOMENT-X    MOMENT-Y    MOMENT-Z
      11     -8.000000E+02  -5.324811E-25  -5.022170E-13  -1.585729E-23  2.379923E-10   5.402913E-11
  
```

The axial force for the second case is negative while for the first case is positive. The reason of this difference is that the CID 1 has its x axis in the same direction that the vector from GA to GB, while the CID 2 has the reverse direction.

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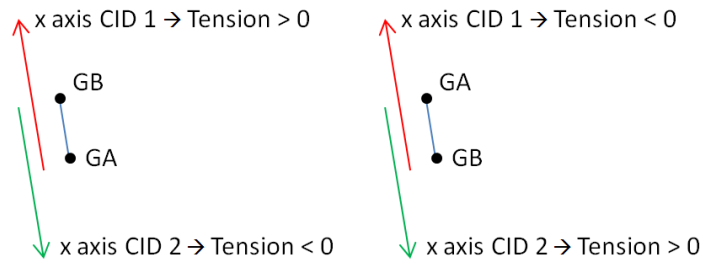


Figure 4: Schematic view for element coordinate system

So, in order to obtain correct results, the x axis must have the same direction than the vector from GA to GB, otherwise the forces should be taken with care, looking at the sign criterion. This is because the element forces are computed as $K \cdot (u_B - u_A)$.

- Length=0 and CID

For this case, all the explanations given in the previous case apply. The only aspect that has to be taken into account is that the CBUSH nodes are coincident. The sense of the out of plane direction must be coherent with the real position of the plates. If the plate A is really over the plate B (although the position of plates A and B is coincident on the FEM), the sense of the CID direction used as element coordinate frame must point downwards (from A to B) in order to get positive forces with tension loads. This is because the element forces are computed as $K \cdot (u_B - u_A)$.

- CELAS case

The NASTRAN code of the example studied must be modified, removing the PBUSH and CBUSH cards and adding the PELAS and CELAS cards displayed below.

```

PELAS 2 100000.
CELAS1 11 2 5 1 14 1
CELAS1 12 2 5 2 14 2
CELAS1 13 2 5 3 14 3
CELAS1 14 2 5 4 14 4
CELAS1 15 2 5 5 14 5
CELAS1 16 2 5 6 14 6

```

As it has been explained in the first chapter, the DOF placed in the CELAS card, are referenced to the nodes analysis coordinate system. This is a really important aspect since it is what CELAS relates.

After running the NASTRAN file, the following results are obtained.

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As it was expected, the displacements of the nodes 5 and 14 are positive ($z > 0$) and the CELAS forces are as follows

ELEMENT ID.	FORCE	FORCES IN ELEMENT ID.	SCALAR FORCE	SPRINGS ELEMENT ID.	(CELAS1) FORCE	ELEMENT ID.	FORCE
11	0.0	12	0.0	13	-8.000000E+02	14	-1.988909E-10
15	1.962440E-11	16	0.0				

The force of the CELAS 13 is negative, although the fastener is working under tension load. That is because the CELAS computes the force using the equation displayed below:

$$F = k(u_A - u_B)$$

Which, for this case leads in the following relation.

$$F = 100000(u_5 - u_{14})$$

As the displacement of the upper node (14) is higher than the displacement of the node (5), then the force is negative.

In order to solve this problem, the best and quickest way is to change the connectivity of the CELAS card. This will give the following configuration.

CELAS1	11	2	14	1	5	1
CELAS1	12	2	14	2	5	2
CELAS1	13	2	14	3	5	3
CELAS1	14	2	14	4	5	4
CELAS1	15	2	14	5	5	5
CELAS1	16	2	14	6	5	6

Below, a schematic view of the most common configurations is shown.



Figure 5: Schematic view for CELAS configuration

Although the easiest way to obtain the correct sign for tension load is to change the connection of the CELAS, it is also possible to reverse the corresponding DOF direction as can be seen in Figure 5.

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It is important that both nodes have the same DOF direction and sense, because otherwise there are some errors in the model.

The best way to see it is with an example. The NASTRAN code used is shown below.

```

PELAS 2 100000.
CELAS1 11 2 5 1 14 1
CELAS1 12 2 5 2 14 2
CELAS1 13 2 5 3 14 3
CELAS1 14 2 5 4 14 4
CELAS1 15 2 5 5 14 5
CELAS1 16 2 5 6 14 6
GRID 5 100. 100. 0. 1
GRID 14 100. 100. 0. 2
  
```

The node coordinate systems of nodes 5 and 14 have been changed. Now the coordinate systems are the 1 for the node 5 and the 2 for the node 14.

The x DOF for both nodes are as the ones shown below:

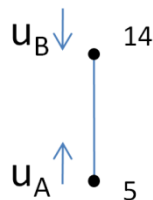


Figure 6: x DOF for nodes 5 and 14

The DOF of both nodes have not the same sense, so, the results will not be the correct. As an example, for a displacement equal of both nodes in positive/negative direction (both inwards/outwards), the resulting force will be null because $u_A - u_B = 0$.

After running the NASTRAN code with this configuration, it is possible to see that both displacements are negative. The nodes displacement are selected by NASTRAN in such a way that the force that has to be transferred is coincident with the value $K \cdot (u_A - u_B)$, but the stiffness really accounted by the model is not the stiffness K .

If the directions used on both nodes are not coincident a lack of equilibrium can be found on the model. A force on direction Y can be balanced by means of forces on direction Z, for example. On these cases the lack of equilibrium is inserted on the stiffness matrix of the model creating grounding of the structure.

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```

PELAS 2 100000.
CELAS1 11 2 5 1 14 1
CELAS1 12 2 5 2 14 3
GRID 5 100. 100. 0. 1
GRID 14 100. 100. 0. 1
  
```

4. CONCLUSIONS

The main conclusions of the previous chapters are going to be listed below:

- CBUSH oriented by means of orientation vector.
Although the length of this element must not be null, the interpretations of the results are always easy. Tension loads leads always to positive forces.

- CBUSH oriented by means of CID.
The length of the element is not important.
For this case, the forces are coherently computed (positive=tension load) only if the corresponding axis of the CID goes in the same direction and sense that the vector from node GA to GB or from the real positions if the nodes GA and GB are coincident. Otherwise, if the corresponding axis goes in the direction from GB to GA, the axial forces must be changed of sign.

- CELAS
For the CELAS components there are two requirements to obtain correct results. The first one is that the DOF of both nodes must have the same direction and sense. And the second one is that the CELAS must relate the nodes in the reverse direction than the nodes DOF. That is, the vector which joints the real plate where is the node A and the real plate where is the node B (the nodes GA and GB must be coincident on the model) is opposite to the DOF. It can be seen easily in the following figure.

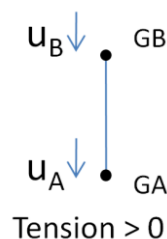


Figure 7: Schematic view for CELAS configuration