Development of Model Simplifications of Bus Body Connections

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Abstract
The simplifications for connections between beams of body frame, although is not enough to affect the stress distribution of the whole bus body frame, is still very important for local stress distribution, especially for stress concentration regions. In this paper, with electronic test technique and the FEM software ANSYS, according to the real structure, we use different ways to simplify the connections to acquire the optimum simplified way and higher calculation accuracy.

Introduction
More and more papers on the FEM modeling of bus body have been published in the world recently. For some cases, some insist that the bus body model should be simplified by beam elements, and some think the plane elements should model the bus body finer, while the others consider the major-minor nodes should be applied for the modeling. The modeling theory about the whole body should be more considerable. However, in the latter FEM analysis, the simplifications between the bus body connections have never been considered in detail. The suitable simplifications about the connections, which will have no visible efficiency on the stress tendency of the whole bus body, is more important for the local stress, especially for stress concentration conditions.

Procedure
Four forms divide the connection style: weld connection, rigid connection, bolt connection and rivet connection. Considering the standard simplification way for the bolt connection in the last papers, it is simplified use two different elements: beam elements and solid elements. So the simplifications for every form are shown in figures 1, 4, 7, 10, and 13. In the modeling, the bus prototype uses a vehicle body that is manufactured by some nation factory. For all models we apply the same or equilibrium constraints, and magnitudes and directions of the applied forces are the same with the bus drive condition.

Analysis
1) Model 1: For the rigid connection simplification we use shell elements to make model, which is figured in Figure 1. In the rigid-connection model simplified by shell elements the attributes of the longitude beam (part) and cross member is the same as the prototype bus. And the load of passengers is applied on the beams in pressure. For this model, the two beams are connected rigid.

2) Model 2: for the weld model, which is figured in Figure 4, in the welded parts in which the two beams connected the constraint coupling technology is applied to simulate the welded point. And there is no connection relation in the other part.

3) Model 3: for this bolt or rivet connection FEM model (A), which is figured in Figure 7, we use the solid elements to simulate the connection relation while there is no other connection between the beams.

4) Model 4: for this bolt or rivet connection FEM model (B), which is figured in Figure 10, we use 16 beam elements to simulate the connection relation in the bolt holes while there is no other connection between the beams.
5) Model 5: for this rigid connection model, which is figured in Figure 13, the beams are used to simulate the relation. In total, there are 4 nodes, 3 beam elements. The section attribute, material attribute and real numbers are equivalent with the shell models.

**Analysis Results & Discussion**

All models apply longitude beam and cross member connection model of the prototype bus. in all models the size of the beams, the constraints applied, the magnitudes and direction of loads are the same as each other.

1) To simplify the models to improve calculation efficient, we make the ends of the beams fixed. The connection between the longitude beams and cross members are applied the constraints as those Models 1-5 shown.

2) According to the design standard of bus chassis, the load, which is equivalent as the weight of 8 standard men, is applied on per square meter area.

After the calculation by ANSYS software, we get these results:

1) For Model 5, which results of the stress and strains is shown in figures 14-15, the maximum stress of the beams is 2.107 MPa, and the maximum nodal strains is 0.004 mm.

2) For Model 1, which results of the stress and strains is shown in figures 2-3, the maximum stress in the beams is 2.232 MPa, which is located the constraint ends of the two beams, and the maximum nodal strains is 0.0039 mm, which is located in the connection area of the two beams.

3) For Model 2, which results of the stress and strains is shown in figures 5-6, the maximum stress in the beams is 27.185 MPa, which is located the welded connection side of the two beams where the pressures are applied, while in the other region the stress level is very low. The whole stress level is shown as 2-3 MPa. And the maximum nodal strain is 0.07 mm, which is located near the welded connection region of the two beams, while in the other regions the stain level is also lower.

4) For Model 3(bolt or rivet connection FEM model A), which results of the stress and strains is shown in figures 8-9, the maximum stress in the beams is 13.6 MPa, which is located the connection side of the two beams where the pressures are applied, while in the other region the stress level is very low. The whole stress level is shown as 2-3 MPa. And the maximum nodal strain is 0.058 mm, which is located near the connection region of the two beams that is same as the area in the welded model, while in the other regions the stain level is also lower.

5) For Model 4(bolt or rivet connection FEM model B), which results of the stress and strains is shown in figures 11-12, the maximum stress in the beams is 15.13 MPa, which is located the connection side of the two beams where the pressures are applied, while in the other region the stress level is very low. The whole stress level is shown as 2-3 MPa. And the maximum nodal strain is 0.060 mm, which is located near the connection region of the two beams that is same as the areas in the welded model and bolt or rivet connection FEM model A, while in the other regions the stain level is also lower.

So we make some conclusions through those calculation results:

1) No matter which model presented in previous paragraphs is applied, the stress distribution and strain tendency that we get from the calculations is same.

2) Compared with the rigid connection models that simulated with beam and shell elements, it is seen clearly that the difference of the maximum stress and strain between the two models can be neglected, and the shell model can present the stress distribution and strain in the construction more precise and finer, while the beam model just present a even result. The result of the even stress distribution and strain in the shell model is same as that in beam model.

3) Comparing the rigid connection model with the other types connection, we can make a conclusion that the regions that have maximum stress and strain in these models are not same. So in the FEM model, it is unsuitable that rigid model replaces the other types connection. When the construction is more complex, it will get a erratic result that we cannot get the true region of maximum stress and strain, and
the true magnitude of the maximum stress and strain, while we just get the tendency of whole stress and strain distribution. Then we are sure that in the initial modeling stages, the rigid connection relation can be used to simplify modeling, but in the next stages the shell model should be used to simulate the practical relation in detail to acquire more precise results.

4) Comparing two bolt or rivet connection models, we can get the conclusion that results from the two models are identical by and large.

5) Comparing three models of weld and bolt or rivet connection, we can conclude that although the tendency, maximum stress distribution region and maximum strain region from models is identical, there are some differences in peak stress and strain, which is because of the characteristics of three models in connections are different. In the weld connection model, there are more welded points and they are located in high density, from which we can think that the constraints in the weld connection model are even distributed. In the other two models, there are so small amount of nodes as connections between the beams that the constraints can be seen as point constraints. So the way of using the weld connection model to simplify the relation between beams can get finer strength distribution although in the fact, the connection strength from weld, bolt or rivet constructrue should be close to equivalent.

In a word, to simplify a connection between bus body frame parts we should have the basis of the fact connection relation. In initial modeling stages using rigid connection to simplify model can improve more calculation efficiency, while in next stages to refine model further, using rigid connection or the other model without attaching importance to the real connection relation between parts, will bring on a erratic result out of question.

Application & Conclusion

We apply the conclusion above in a analysis based on some a domestic bus. The graphs of models are shown in Figures 16-17.

In the model of Figure 16, we use the FEM software ANSYS, based on the effective experience of former modeling, to simplify and model. Because whole body frame is welded by rectangle section iron parts and pressings, some simplifications are made below:

1) The functional parts and unload parts are neglected.
2) Two close but not coincidence nodes are treated as a node.
3) Shapes of some sections are simplified appropriately. Simplify to the best of the abilities the features that will not affect much section attributions, for example, the small holes, slots, titles, circular beads, etc.

Treatment of boundaries

We use the rigid beams-flexible beams structure to simulate leaf spring suspension, in which the flexible amount of tires is neglected.

In bend case, Z translations of all four wheels are constrained, the other DOFs of left front wheel are constrained, X translation of right front wheel and Y translation of right rear wheel are also constrained. In

Twist case with left rear wheel hung in the air, the six DOFs of left front wheel are constrained, X and Z translations of right front wheel and Y and Z translations of right rear wheel are hold.

The equivalent graph of the rigid beams-flexible beams structure is shown in Figure 17. Bend strength of horizontal flexible beams are equivalent with the fact spring rate K, while the axis rate of the rigid beams is assumed as 500000N/mm, to make their axis displacements much smaller than the vertical displacements of flexible beams. The section of the rigid beams is assume as square, which area can be get from the equation below:

\[
A = \frac{5.0 \times 10^5 \times L}{E}
\]
where: A-the section area of rigid beam

\[ L \text{- the length of rigid beam, according to the fact structure, is assumed as 200mm;} \]

\[ E \text{- Young's modulus, assumed as } 2.06 \times 10^5 \text{N/mm}^2 \]

So the side length of rigid beam is 22mm after calculation. The section of flexible beams is also assumed as square, in which \( h \) presents the side length of the section. Through the equation of the deflection, we can induce the next equation:

\[
h = 4 \sqrt[4]{\frac{KL^3}{2E}}
\]

where \( K \)-the spring rate of leaf spring

\( L \)-the distance between front and rear spring eyes center of the spring

Because of the already known \( K \) and \( L \) of spring, we get : \( h_{\text{前}}=35.5\text{mm}, h_{\text{后}}=50\text{mm} \).

**Treatment of loads**

1) Input the material density and gravity acceleration in the preprocessor module to apply the weight of the body frame.

2) Apply the weights of passengers and chairs in respective location. Considering the weight of window frames, assume a coefficient of the window glass weight \( k=1.2 \). The corrected loads are applied on the respective parts of the breast beams in pressure. The weights of assemblies in the chassis based on the theory of equivalence are applied in force on the fact locations.

**Selection of cases**

1) Bend case:

The bus is in the horizontal and full-load position. The loads are applied in vertical direction. This case is just used to simulate the bus standard travel situation.

2) Wrist case:

There are several projects in selecting the case.

- Project 1: a front wheel is lift up 200mm, while a rear wheel is held down 200mm;
- Project 2: front wheels or rear wheels are lift up or held down 240mm simultaneously;
- Project 3: one wheel is lift up or held down 240mm or hung in the air;

The test condition limits Project 1 not to carry out. And in Project 2 the stress state is not worse than the other projects. So during the test and modeling, Project 3 is adopted. Because the prototype bus has rear engine, the case of rear wheel hung in the air should be more critical than the case of front wheel hung. Then the case of left rear wheel hung in the air is selected as twist case.

However, we select shell elements to discrete body frame and apply respective weld constraints on every connection beam for weld model shown as Figure 17. the case, boundary, constraint and loads are same as above.

**Analysis results**

For model 1(shown as Figure 16):

In twist case, the stress level is much higher than that in bend case. But the number of elements which element stress is higher than 50Mpa is 116, which is just 8.66 percent of total element number. The element
has maximum stress locates in the upper frame part of mid-door frame. From the result of calculation, we can get the even stress level of total body frame is appropriate 30Mpa. The regions with stress concentration is indicated below:

(1) The region near mid-door upright columns;
(2) The region near upright columns and up beams in the left side against to mid-door;
(3) The region in the window columns of left and right side.

For model 2 (shown as Figure 17):
In twist case, from the result of calculation, we can get the even stress level of total body frame is appropriate 30Mpa. But the number of elements which element stress is higher than 50Mpa is 238, which is percent 17.8 of total element number. The element has maximum stress (120MPa) locates in the connection between rear upper frame part of mid-door frame and right upper beams. The regions with stress concentration is indicated below:

(1) The region near mid-door upright columns;
(2) The region near upright columns and up beams in the left side against to mid-door;
(3) The region in the window columns of left and right side.

Comparison Analysis results with test results

This test keeps strictly to stress test national standard of bus body frame. The test includes bend case and twist case (the left rear wheel hung in the air) while the bus is full loaded. The results are shown below:

In twist case, the regions with stress concentration locate near mid-door upright columns, upright columns and up beams in the left side against to mid-door and the window columns of left and right side. the total stress level is high. The region with maximum stress 118.9 Mpa locates the lower face of connection between right upper beam and mid-door upright column. The number of test points with their stress beyond 50Mpa is 15. for the floor frame, its main function is to bear the weights of all passengers and translate it to frame assembly. So in the test the parts of the floor assembly have a low stress level, which has no test point with stress higher than 50Mpa in the bend case and no-load twist case, while which have two test points with stress 59.7Mpa and 54.9Mpa in full-load, rear left wheel hold-down case.

Comparing it with the calculation results, we find that the regions with stress concentration in model 2 are coincide with the results from test, with little difference in magnitude, while the results from model 1 are less precise in both locating the stress concentration region and indicating maximum stress. Because of adoption of shell elements in model 2, the number of elements with higher stress increase, however, these elements are main from the connection parts of body frame. It has been proved by the test that some elements stress in the frame will exceed 50 Mpa. It accounts for how the weld connection refine the bus FEM model from the other side.

Conclusion

From the test and modeling above, we can made a conclusion that to simplify a connection between bus body frame parts we should have the basis of the fact connection relation. In initial modeling stages using rigid connection to simplify model can improve more calculation efficiency, while in next stages to refine model further, using rigid connection or the other model without attaching importance to the real connection relation between parts, will bring on a erratic result out of question.
Figure 1 - rigid connection FEM model of shell elements

Figure 2 - stress map of rigid connection FEM model of shell elements
Figure 3 - strain map of rigid connection FEM model of shell elements

Figure 4 - weld connection FEM model of shell elements
Figure 5 - stress map of weld connection FEM model of shell elements

Figure 6 - strain map of weld connection FEM model of shell elements
Figure 7 - bolt or rivet connection FEM model A of shell elements

Figure 8 - stress map of bolt or rivet connection FEM model A of shell elements
Figure 9 - strain map of bolt or rivet connection FEM model A of shell elements

Figure 10 - bolt or rivet connection FEM model B of shell elements
Figure 11 - stress map of bolt or rivet connection FEM model B of shell elements

Figure 12 - strain map of bolt or rivet connection FEM model B of shell elements
Figure 13 - rigid connection FEM model of beam elements

Figure 14 - stress map of rigid connection FEM model of beam elements
Figure 15 - strain map of rigid connection FEM model of beam elements

Figure 16 - model 1 made of beam elements
Figure 17 - model 2 have welded connection constrains

Figure 18 - equivalent sketch map of a suspension using rigid-beams and flexible beams structure