Effects of Diagonal Braces on Dynamic Performance of the Van Carriage Frame

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Abstract. In this paper, the modal analysis of the van carriage frame is carried out, the natural frequency and vibration modes of the frame are compared, and the effects of the diagonal braces on the dynamic performance of the van carriage frame is studied by comparing the natural frequency and the vibration modes of the frame, under the condition of no diagonal brace and welded diagonal braces. The research shows that welding diagonal brace is beneficial to improve the overall dynamic stiffness of the van carriage frame. The results of this paper have theoretical reference value for the van carriage frame design.

1. Introduction

The van is mainly used for the full-sealed transportation of all kinds of goods, and the special kind of van can also transport chemical dangerous goods. The van has the characteristics of rain-proof, dust-proof, bacteria-proof, heat-insulating, safe, environment-friendly and all-weather transportation means with high efficiency and quick function compared with the ordinary trucks. In the outline of Road Transportation Development Plan formulated by the Ministry of Communications in 2001, it was clearly pointed out that freight transport should vigorously develop vans, speed up the transition from an ordinary open truck to a van, and realize the unexposed transport of goods. Chinese five ministries have also jointly issued a paper on medical wastes and other transport vehicles to put forward strict restrictions on closed transport. Therefore, the importance of van has been highlighted, in recent years its market share has increased year by year.

Carriage is the main component of vans, it must have enough strength and static stiffness to meet its service life and safe driving requirements, at the same time, it should also have reasonable dynamic characteristics to achieve the purpose of controlling vibration and noise. In the design of carriage structure, if only the static strength and stiffness of the structure are considered, the local structure of the carriage may be unreasonable in the process of design, which will lead to resonance and noise in the interior of the vans. Modal analysis, as the basis of dynamic analysis, is an important content of dynamic analysis. Modal analysis is used to calculate the natural frequency of the carriage frame structure and determine the vibration mode, so as to judge the whole or local stiffness of the structure. Natural frequency and vibration mode vector are necessary parameters in the dynamic performance design of the vehicle body structure[1, 2, 3].

At present, some of the larger vans will be welded some diagonal braces (also known as diagonal stiffeners) in the front side, left side, right side of the van carriage frame, as shown in figure 2, but some will not. The main reason is that in the van manufacturing industry, the application of welding
diagonal braces to the van carriage frame is only based on experience, with some blindness. Therefore, it is of great practical significance to study the effects of diagonal braces on the performance of carriage frame. In this paper, the modal analysis of the carriage frame is carried out, the natural frequency and vibration modes in the case of welding diagonal braces and no diagonal braces are compared, and the effects of the diagonal braces on the dynamic performance of the van carriage frame is studied. The purpose of this paper is to provide a theoretical basis for the design of van carriage frame.

2. The finite element modeling of the van carriage frame
This paper takes a common van in a manufacturing factory as the object of the study. The van adopts the second-type chassis with a flat head diesel truck cab, the full load weight of the van is 11 tons, and the design load weight of the carriage is 6 tons. The carriage frame is all steel structure, and the carriage is composed of longitudinal beams, cross beams, posts, roof beams, etc. The length of the van is 6080mm, the width is 2400mm, the height is 2100mm. The finite element model of the van carriage frame structure is established by using the finite element analysis software Ansys and the beam element (Beam188). The finite element models of the van carriage frame without diagonal brace and with diagonal braces are shown in figure 1 and figure 2 respectively. During the modeling process, in order to avoid making that problem too complex, on the premise of reflecting the main mechanical characteristics of the van carriage frame structure as far as possible, appropriate simplification measures have been taken for the model. For example, some non-bearing parts which have little effect on the structural deformation and stress distribution of the whole vehicle are ignored; do not take into account the effect of the corrugated plates of the van carriage; straightening out the micro-curved beams in the van carriage; merge the very close nodes.

![Figure 1. The van carriage frame without diagonal brace.](image1)

![Figure 2. The van carriage frame with diagonal braces.](image2)

3. The calculation and analysis of the van carriage frame
In this paper, the modals of the two models of the van carriage frames without diagonal brace and with diagonal braces were calculated and analyzed. Using the Block Lanczos modal extraction method included in the Ansys software, the natural frequencies and the vibration modes in no-load and free state were extracted. The specific frequency values are shown in table 1 and the vibration modes are shown in table 2, figure 3-figure 10 (limited by article length, only the vibration modes of these orders are listed). Although the low order modes of the first 10th-order or the lower order modes of the first 16th-order are more concerned in the vehicle modal analysis [4, 5, 6], in order to study the effects of the diagonal braces on the mode of van carriage frame, the first 20th-order modes of the van carriage frame are studied in this paper.
3.1. Effects of the diagonal braces on the natural frequencies of the van carriage frames

Table 1. Comparison of the first 20-order natural frequencies of the van carriage frames without diagonal brace and with diagonal braces

| order | the frequency without diagonal brace (Hz) | the frequency with diagonal braces (Hz) | frequency change rate after welded diagonal braces (%) |
|-------|-----------------------------------------|---------------------------------------|----------------------------------------------------|
| 1-6   | 0                                       | 0                                     | 0                                                  |
| 7     | 5.478                                   | 5.935                                 | 8.34                                               |
| 8     | 13.294                                  | 12.750                                | -4.09                                              |
| 9     | 15.602                                  | 12.757                                | -18.23                                             |
| 10    | 15.696                                  | 13.089                                | -16.62                                             |
| 11    | 16.972                                  | 13.089                                | -22.88                                             |
| 12    | 19.872                                  | 13.660                                | -31.26                                             |
| 13    | 22.832                                  | 13.712                                | -39.94                                             |
| 14    | 23.512                                  | 13.871                                | -41.00                                             |
| 15    | 25.498                                  | 13.874                                | -45.59                                             |
| 16    | 26.896                                  | 13.919                                | -48.25                                             |
| 17    | 28.046                                  | 13.948                                | -50.27                                             |
| 18    | 28.736                                  | 13.955                                | -51.44                                             |
| 19    | 30.167                                  | 14.081                                | -53.32                                             |
| 20    | 30.739                                  | 14.090                                | -54.16                                             |

As can be seen from table 1, the natural frequency range of the van carriage frame without diagonal brace is in 5.478 Hz-30.739 Hz; the natural frequency range of the van carriage frame with diagonal braces is in 5.935 Hz-14.090 Hz. In both cases, the natural frequencies are higher than the normal road excitation frequency (3 Hz). In addition, it is necessary to compare the vibration of the engine which is another important excitation source for the carriage vibration. Because this van is equipped with a in-line 4-cylinder 4-stroke diesel engine, according to the idling excitation frequency of the engine, the calculation formula is as follows:

\[ f = \frac{2nz}{60\tau} \]

in the formula, n is the speed of the engine, z is the number of cylinders, and \( \tau \) is the number of strokes of the engine.

The idling speed of the engine is 700 \( \pm 50 \) r / min, according to the above formula, it can be calculated that the idle excitation frequency of the engine is in the range of 21.6 Hz- 25 Hz, and the excitation frequency of the engine is much higher than this range when the vehicle is running normally. Therefore, it can be seen from table 1 that the natural frequency of the carriage frame without diagonal brace is lower than the minimum value of the idle excitation frequency of the engine within the 12th order, and the frequency of the carriage frame with diagonal braces is all lower than the minimum value of the idle excitation frequency of the engine in less than 20 orders. Considering the effect of the lower order natural frequency on the dynamic characteristics of the van carriage is greater, many papers have only calculated the natural frequencies of the first 10 orders[]. According to Table 1, within the range of the first 10 orders, the natural frequency of the van carriage frame with or without diagonal braces is lower than the minimum value of the idle excitation frequency of the engine. That is to say, the natural frequency before and after the welding diagonal braces on the van carriage frame is not equal to that of the common excitation source, so the resonance of the van carriage frame can be avoided.

It is worth noting that, the natural frequency of van carriage frame without diagonal brace increases obviously with the increase of order, while the natural frequency of the van carriage frame with the diagonal braces increases only slightly with the increase of the order. Except for the frequency of the 7th order, the natural frequency of the van carriage frame after welding is reduced, and the larger the order is, the greater the amplitude of the decrease is. That is, welding diagonal braces can reduce the
natural frequency of the van carriage frame in most cases, which is beneficial to stagger the excitation frequency of engine.

3.2. Effects of the diagonal braces on the vibration modes of the van carriage frames

Table 2. Comparison of the first 20-order vibration modes of the van carriage frames without diagonal brace and with diagonal braces

| order | the vibration modes without diagonal brace | the vibration modes with diagonal braces |
|-------|-------------------------------------------|----------------------------------------|
| 1-6   | Vibration mode of rigid body               | Vibration mode of rigid body            |
| 7     | The frame presents a first-order torsion,  | The frame presents a first-order torsion, |
|       | as shown in figure 3                       | as shown in figure 4                    |
| 8     | The frame presents a first-order lateral   | The rear of both sides present locally  |
|       | bend; the vibration amplitude of the upper | first-order lateral bends with a larger |
|       | part of the two sides is larger, it's a    | vibration amplitude, and the bending    |
|       | modal peak / valley, as shown in figure 5. | direction of the two sides is the same,|
| 9     | The frame presents a first-order slight    | as shown in figure 6.                   |
|       | torsion; two sides present a second-order  | The rear of both sides present locally   |
|       | vertical bends and show one front and one  | first-order lateral bends with a larger |
|       | rear, as shown in figure 7.                | vibration amplitude, and the bending    |
| 10    | The frame presents a second-order vertical | direction of the two sides is opposite, |
|       | bend, as shown in figure 9.                | as shown in figure 8.                   |
|       | The frame presents a first-order vertical  | The rear of both sides present locally   |
|       | bend; the vibration amplitude of the middle | first-order lateral bends with a larger |
|       | part of the two sides is larger, it's a     | vibration amplitude, and the bending    |
|       | modal peak / valley.                       | direction of the two sides is the same. |
| 12    | The frame presents a first-order torsion;  | The vibration mode is similar to the 11th |
|       | both sides have a vertical first-order bend | order with diagonal braces.             |
|       | and present one front and one rear.        | The rear of both sides present locally   |
|       | Both sides presents a lateral second-order  | first-order lateral bends with a larger |
|       | bend respectively, the vibration amplitudes | vibration amplitude, the other part of   |
|       | of the upper part of both sides are larger, | both sides presents locally slight       |
|       | they are the modal peak / valley; both sides | second-order lateral bends, and the     |
|       | also present locally lateral fourth-order   | bending direction of the two sides is    |
|       | bends.                                    | opposite.                              |
| 13    | The frame presents a second-order lateral   | The front parts of both sides present   |
|       | bend; both sides present a first-order      | locally first-order lateral bends with  |
|       | vertical bends, and the bending direction   | a larger vibration amplitude, the rear  |
|       | of the two sides is opposite; the          | of both sides presents locally slight    |
|       | vibration amplitude of the middle of both  | second-order lateral bends, and the     |
|       | sides are larger, they are the modal peak  | bending direction of the two sides is    |
|       | / valley.                                 | the same.                              |
| 14    | The roof presents a vertical first-order    | The front parts of both sides present   |
|       | bend locally; both sides present locally    | locally first-order lateral bends with  |
|       | slight first-order lateral bends.          | a larger vibration amplitude, and the   |
| 15    | The front and rear of both sides present   | bending direction of the two sides is    |
|       | respectively first-order and third-order    | opposite.                              |
|       | lateral bends locally; both sides present  | The front parts of both sides present   |
|       | slight first-order vertical bends and the   | locally first-order lateral bends with  |
|       | bends between the two sides are staggered  | a larger vibration amplitude, and the   |
|       | back and forth.                            | bending direction of the two sides is    |
| 16    |                                           | opposite.                              |
Both sides present fourth-order lateral bends locally.

The vibration mode is almost similar to the 17th order without diagonal brace, but the deformation is slightly smaller.

One side wall presents locally fourth-order lateral bends with a larger vibration amplitude, the front side presents slight longitudinal bends.

The rear of both sides present second-order lateral bends locally, and the bending direction of the two sides is opposite.

The front side presents locally first-order longitudinal bends with a larger vibration amplitude.

The middle and lower part of both sides present locally first-order lateral bends with a larger vibration amplitude, and the bending direction of the two sides is the same.

Note: Lateral bend refers to bending along the transverse axis (Y axis), vertical bend refers to bending along the vertical axis (Z axis), longitudinal bend refers to bending along the longitudinal axis (X axis), torsion refers to torsion around the longitudinal axis (X axis).
Figure 7. The 9th-order vibration mode of the van carriage frame without diagonal brace.

Figure 8. The 9th-order vibration mode of the van carriage frame with diagonal braces.

Figure 9. The 10th-order vibration mode of the van carriage frame without diagonal brace.

Figure 10. The 10th-order vibration mode of the van carriage frame with diagonal braces.

As shown in tables 2 and figure3-figure 10:

For the van carriage frame without diagonal brace, the 1st-6th order vibration modes are all rigid body modes, all of the 7th-14th order vibration modes present a whole or a wide range of bending or torsion, the 15th-20th order vibration modes are all local bends.

For the van carriage frame with diagonal brace, the 1st-6th order vibration modes are all rigid body modes, in addition to the whole frame torsion of the 7th-order vibration mode, all of the 8th-14th-order vibration modes do not present a whole or a wide range of bending or torsion, and all of which only present the local bends. That is, after welding diagonal braces, the bending or torsion of the van carriage frame disappears in the 8th-14th order vibration modes.

In the first 10th-order or the first 16th-order vibration modes which are of great concern of automobile modal analysis, the low-order and lower-order vibration modes of the van carriage frame can be effectively improved by welding diagonal braces.

4. Conclusions

In this paper, the modal analysis of the van carriage frame in the case of welding diagonal braces and no diagonal braces is carried out. The results show that:

(1) Welding diagonal braces can reduce the natural frequency of the van carriage frame in most cases, which is beneficial to stagger the excitation frequency of engine.

(2) Welding diagonal braces can reduce the whole or a wide range of bending or torsion vibration modes of the van carriage frame, and the low-order and lower-order vibration modes can be effectively improved.

In general, welding diagonal braces are beneficial to improve the overall dynamic stiffness of the van carriage frame.
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