PRACTICAL GLOBAL-LOCAL DESIGN OPTIMIZATION OF VEHICLE BODY-IN-WHITE STRUCTURES

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ABSTRACT

In structural analysis and optimization, local design features often will have a driving effect on global structural responses. Capturing the design possibilities in a manner that is useful to the optimizer may, however, result in physical designs that are unreasonable from a manufacturing point of view.

Vehicle body-in-white structures are a good illustration of this global-local phenomenon. Although the stiffnesses of the vehicle's joints strongly influence the global modes, the optimizer may have difficulty making design decisions owing to the detail inherent in the joints' description. Design variable linking is the obvious solution to the problem but it, in a sense, forces a constraint on the type of redesign the optimizer can perform.

In this paper, MSC/NASTRAN's design optimization capabilities, coupled with image superelements for the vehicle's joints are used to tune the global modes of a complex vehicle structure, while providing joint stiffness targets for subsequent local redesign.

INTRODUCTION

In the design of vehicle body-in-white structures, significant attention is given to the characteristics of the fundamental frequencies. Lower order modes have a pronounced effect on ride and handling and good NVH characteristics; among other possible engineering changes, increasing the eigenvalues of these fundamental frequencies often enhances the customer’s perception of the vehicle by giving it a more "solid" road feel as well as improving the common low frequency problems like seat shake and steering column shake. However, added stiffness often comes at the expense of vehicle weight.

The global response of the lower order modes is often strongly affected by the design of the vehicle’s joints, for example the a-pillar to roof, b-pillar to floor, cross-member to rail, and so on. Changes to these joints can often be made with very little change in the structure’s overall weight. In optimization terminology, we can say that the sensitivity of the eigenvalues to changes in the overall joint stiffness is quite high, while the corresponding weight sensitivity is low.

Even though the overall joint eigenvalue sensitivity may be high, the sensitivities to the individual properties that make up the joint are usually quite low. This, combined with the low weight sensitivity may create numerical problems during optimization. Attempting to minimize the weight subject to constraints on eigenvalues may not produce the most meaningful results due to the independent nature with which the optimizer can change the joints. Design variable linking yields a satisfactory solution to the problem, and this paper will outline one possible method for this.

Another difficulty in joint stiffness design lies in the eventual manufacture of the particular joint. Designers are often interested in target stiffnesses, rather than the optimal properties generated by the optimizer. These stiffnesses can be used to evaluate the relative merit of other local design changes. In this paper, image superelements will be used to help extract some standard joint stiffnesses.

METHODOLOGY

Effective joint stiffness design depends on the solution of two practical problems; addressing the low response sensitivities due to individual thickness changes, and deriving target stiffnesses for use in redesign efforts.

The low response sensitivities can be overcome by effective use of design variable linking. Assume we start with a collection of thicknesses that describes the initial design of a joint. We can scale these thicknesses up or down using a single design variable to do so as:

$$x_d = c \cdot x_i \qquad d = 1,...,ndv \tag{1}$$

Where x_d is the thickness of one of the plate element groups in the model (to which many elments may belong), and x_i is the independent design variable responsible for the scale change in the joint. There is one independent variable per joint, and ndv dependent thickness. Using symmetry to further link joints across the structure further improves the conditioning of the problem. Note that equation (1) describes the curves of an ndv family of thicknesses all passing through the origin of the x_d - x_i plane with slopes c. The answer the optimizer yields will decribe the optimal proportional scaling of the joint. Even though this represents a constraint on the final design, it is felt to be an acceptable one.

Since the design engineer works in terms of joint stiffnesses and not optimal joint properties, the optimal joint thicknesses found by the optimizer must be translated into optimal joint stiffnesses.

Using MSC/NASTRAN's solution 200 capabilities, which supports superelement design optimization, each joint can be modelled as a superelement, and an image of this superelement, along with boundary conditions to simulate the test structure, can be used to extract the stiffness in DMAP. This is essentially a global/local analysis; the joint properties are modified in order to achieve global mode targets, while the local stiffnesses are subsequently extracted for design purposes. The use of an image superelement, to extract the joint stiffnesses, separates this part of the problem from the optimization and does not affect the actual structure.

Figure-1 shows a typical joint and, for clarity, the corresponding disjoint image superelement. The faces of the image are constrained using RBE2 elements that are tied into a single grid per face. With DMAP, the a-set stiffness, K_{aa} is extracted for each such image, and unit moment loads are applied in the particular directions of interest. The resulting deformations under these unit loads provides the necessary compliance information.

APPLICATION

EXAMPLE 1

As mentioned above, joints play an important role in determining the overall stiffness and fundamental body modes of a body-in-white vehicle structure. These fundamental structural modes are crucial for achieving good vehicle NVH and durability characteristics. Figure-2 shows some of the major joints in an automobile body structure.

In this example, the objective is to optimize the first overall torsion mode of a BIW vehicle in terms of the local stiffnesses of the joints. The FE model is a full detailed plates and shell model as shown in Figure-2 and has 142,000 nodes and 145,000 elements.

The first overall torsion mode of the structure was extracted using MSC/NASTRAN Sol. 103 and is 24.4 Hz. as shown in Figure-3. This is less than the objective of 25 Hz.

In this study, the effect of the above mentioned joints on the overall torsion mode will be determined. The optimization results are in terms of the local stiffnesses of these joints required to achieve the global objective of 25 Hz. which are, in effect, the joint stiffness targets that the design engineer has to achieve to meet the full vehicle targets set for the vehicle.

PROCEDURE DETAILS

An image superelement is generated from the data of each joint superelement, and enters the model as a disjoint structure. To each face of the image superelement are added RBE2 elements that collect all face degrees of freedom to a single grid. Via DMAP, the stiffnesses at each of these face grids are recovered and used to extract lumped stiffnesses for each joint. Since each image superelement is disjoint from the model, it has no effect on the overall optimization; it is used for stiffness recovery purposes only. Since it is derived from the primary superelement, which is varied by the optimizer, note that its mass and stiffness values will also be updated.

MSC/NASTRAN SOL 200 is used to perform optimization to achieve the objective of 25 Hz. for the first torsional mode. Design variable linking is used to set up a single independent design variable for each joint. The optimizer essentially uses this independent quantity to uniformly scale the joint to best satisfy global modal requirements. The input deck for SOL 200 is provided in Table-1 which shows the design linking for one joint. SOL 200, with the DMAP alter for stiffness output, yields a final design that satisfies global modal requirements, and provides initial, and "optimum target" joint edge stiffness values that the designer could at least use as a starting point. The initial joint stiffness output for one leg of the joint, as shown in Table-2, is for rotations about x, y and z which give the inboard-outboard, fore-aft and torsional stiffness of the joint. The optimized stiffness values are listed in Table-3 and the optimized gages are listed in Table-4.

EXAMPLE 2

In this example, the objective is to increase the frequency of the local fore-aft mode of a frame cross-member as shown in Figure-4 and to determine the stiffness of the cross-member to rail joint required to achieve the target of 47.0 Hz. The initial frequency is 43.7 Hz.

Again, applying the procedure explained above, the optimizer achieved the target with the initial and final joint stiffness values as the output.

CONCLUSIONS

As shown in the examples, design variable linking coupled with image superelement to extract joint stiffnesses, can be successfully used to tune the global modes of the structure, while providing joint stiffness targets for subsequent local redesign. The designer, thus, can utilize these joint stiffness values as the starting point, to design best-in-class NVH vehicle.

ACKNOWLEDGEMENT

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REFERENCES

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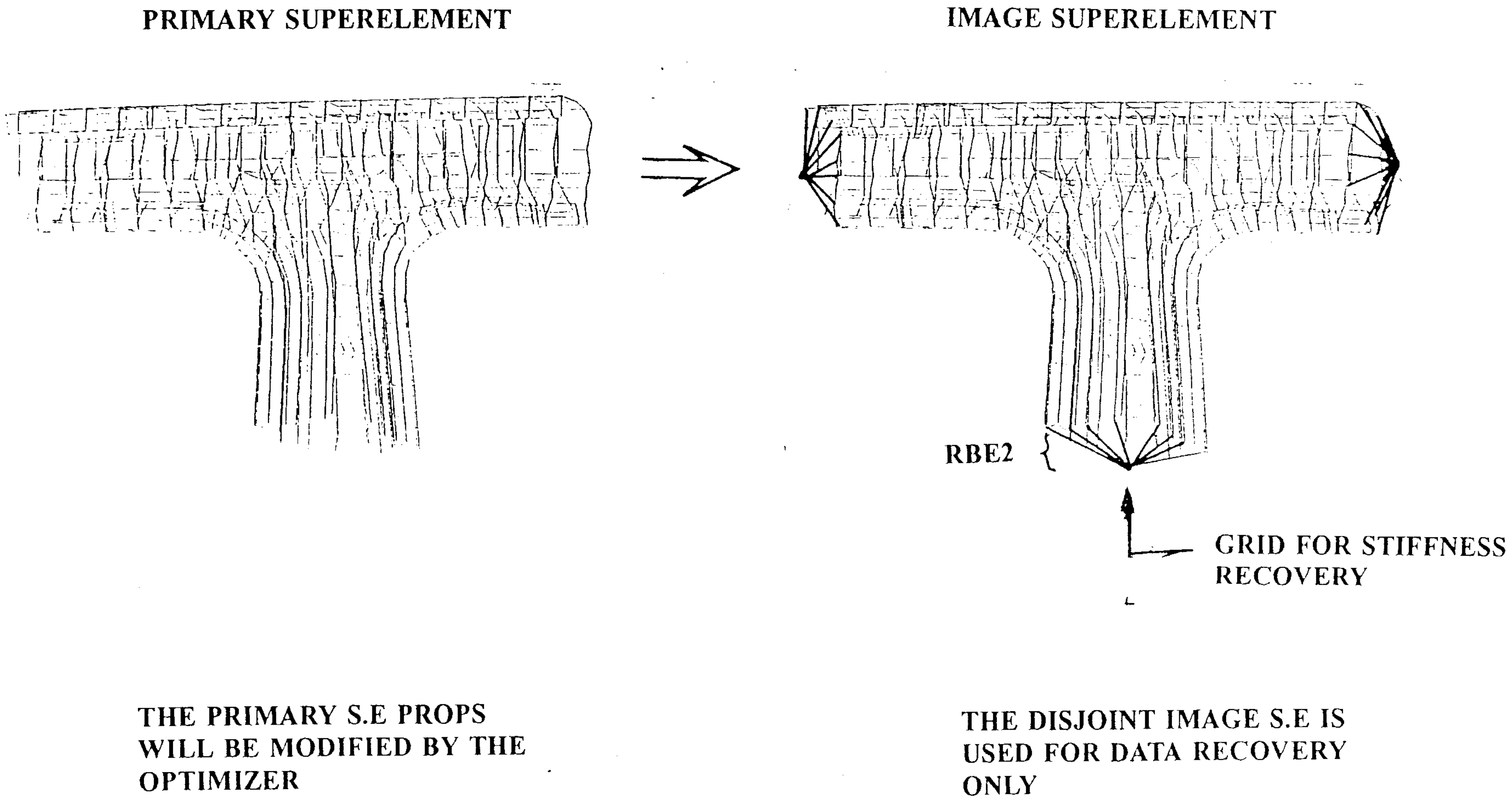

THE PRIMARY S.E PROPS WILL BE MODIFIED BY THE OPTIMIZER

THE DISJOINT IMAGE S.E IS USED FOR DATA RECOVERY ONLY

Figure 1 A typical joint as the primary superelement along with image superelement

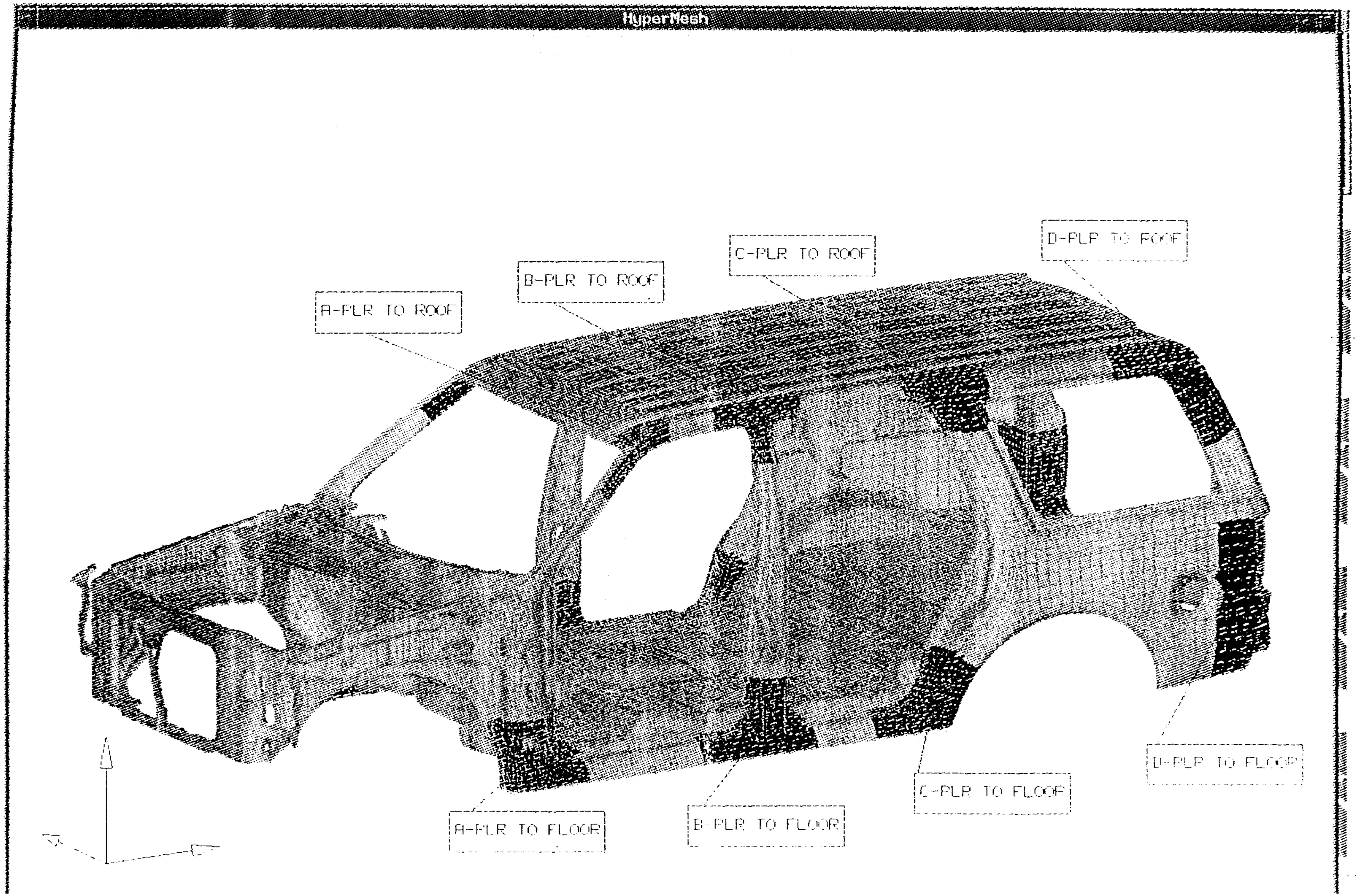

Figure 2 Vehicle BIW model with typical joints

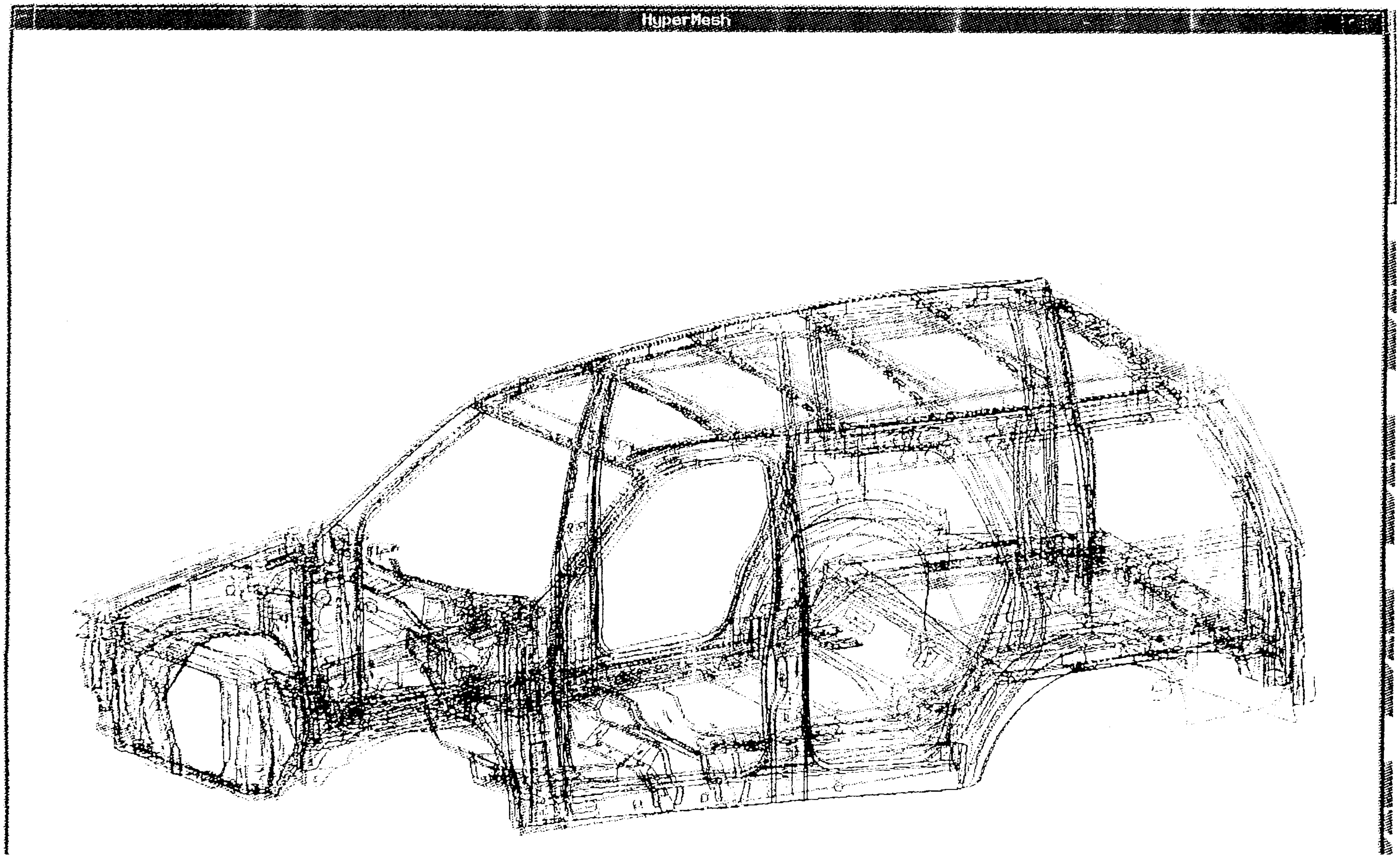

Figure 3 First overall BIW torsion mode at 24.4 Hz

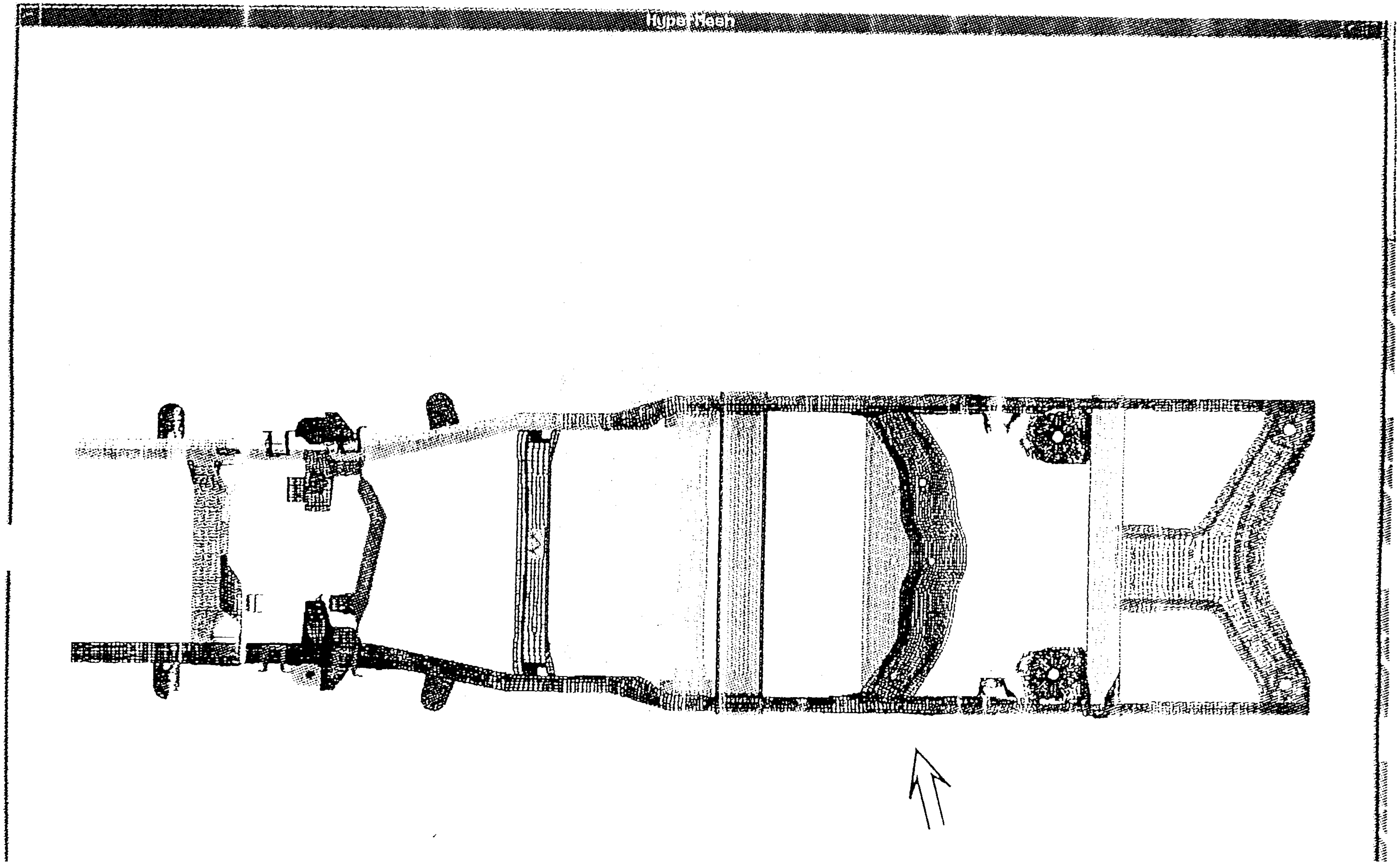

Figure 4 Frame model with local cross member mode at 43.7 Hz

Table-1 Input deck for MSC SOL-200

```
DCONSTR       10      10 2.500E4 2.547E4
DRESP1,10,MODE10,EIGN,,,10
DRESP1,1000,WEIGHT,WEIGHT,,,,,ALL
$
$B-PLR TO ROOF JOINT
DVPREL1     3014  PSHELL    3014       4                                +SO116
+SO116      3014     1.0
DESVAR      3014 PID3014     .85     .35    2.85
$
DVPREL1     3032  PSHELL    3032       4                                +SO117
+SO117      3032     1.0
DESVAR      3032 PID3032     .90     .40    2.90
$
DVPREL1     3131  PSHELL    3131       4                                +SO118
+SO118      3131     1.0
DESVAR      3131 PID3131    2.00    1.50    4.00
$
DESVAR      4003 BPLR2RF     1.0     .50    4.00
DLINK       3014    3014     0.0     1.0    4003     .85
DLINK       3032    3032     0.0     1.0    4003     .90
DLINK       3131    3131     0.0     1.0    4003     2.0
```

Table-2 Initial joint stiffness values

```
0      MATRIX KKUU     (GINO NAME 101 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
      1)    8.7506E+06
0      MATRIX KKVV     (GINO NAME 102 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
      1)    5.3026E+07
0      MATRIX KKWW     (GINO NAME 103 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
      1)    2.3898E+07
```

Table-3 Final joint stiffness values

```
0      MATRIX KKUU     (GINO NAME 101 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
      1)    1.1260E+07
0      MATRIX KKVV     (GINO NAME 102 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
    ROW
      1)    6.5222E+07
0      MATRIX KKWW     (GINO NAME 103 ) IS A REAL
0COLUMN      1      ROWS      1 THRU      1
    ROW
      1)    2.9444E+07
```

Table-4 Design cycle history

```
                ***********************************************************************
                S U M M A R Y   O F   D E S I G N   C Y C L E   H I S T O R Y
                ***********************************************************************


-------------------------------------------------------------------------------------------
 INTERNAL  |EXTERNAL    |             |
DV. ID.  | DV. ID.  |   LABEL   | INITIAL      :      1       :      2       :      3
 ------------------------------------------------------------------------------------------
        3 |    4003    | BPLR2RF  | 1.0000E+00 : 8.5401E-01 : 9.2845E-01 :
       28 |    3014    | PID3014  | 8.5000E-01 : 8.5189E-01 : 9.9628E-01 :
       34 |    3032    | PID3032  | 9.0000E-01 : 9.0200E-01 : 1.0549E+00 :
       40 |    3131    | PID3131  | 2.0000E+00 : 2.0044E+00 : 2.3442E+00 :
```