Development of New Articulated Structure and Bogie for Korean High Speed Train (HSR-350X)

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Abstract
A Korean High Speed Train (hereafter, HSR-350X), which is of an articulated train to be similar to TGV, has been developed and built by the Korean consortium since 1996. For improvement of HSR-350X, we have developed the horizontal articulated structure with new concept in comparison with the existing of vertical type. Due to the new articulated structure, automatically a bogie with four air spring system also has been developed newly to mount properly beneath the articulated structure. The articulated structure and bogie was designed through a dynamic and strength analysis. To prove the design, we have carried out many tests. Bogie frame has passed the fatigue test of the cycles of 10 millions according to UIC 515-4. And the articulated structure with rubber element has had the dynamic test of 4 millions cycles. After the test, no crack was appeared on the articulated structure. Lastly, during the running the HSR 350X on high speed line, safety and instability of new developed bogie was measured. It was assessed to be within the limits according to UIC 518.

Introduction
Since 1996, a Korean consortium composed of Hyundai Rotem Company and other Korean industrial companies, Research and development institutes and universities, has been developing a new articulated high speed train: the HSR-350X. During testing, in 2004, a HSR-350X unit consisting of seven (7) cars has recorded a speed of over 352 km/h. Since then, the train has undergone a 200,000Km reliability test program. The new inter-car articulation of the HSR-350X is a novel design and maintenance friendly with easy access for assembly/disassembly operations and routine visual inspections. The new articulation assembly retains the same functions as the original design but is simpler, more compact. A new bogie was also developed to accommodate the new articulation arrangement. The design characteristics of the articulation structure and bogie were defined and assessed with a dynamic analysis of the entire consist. Their structural integrity was evaluated and tested according to UIC 515-4, UIC615-4, UIC 566 and EN12663. A new articulated structure and a bogie were then manufactured and installed at one inter-car interface of the existing HSR 350X. The safety and stability performances of the system was monitored and assessed according to UIC 518 during high speed line running tests.

Selection of new articulated structure and bogie
The existing articulated structure relies on a vertical joint type design, large casting structures mounted on the end of each interfacing cars interlocking with each other along the centre line of the train. The pin joint type interlock equipped with a vertical laminated rubber cone allows relative movements, governed by the track curvatures, between two consecutive cars. Either side of articulation, a suspension air spring is located. Due to this arrangement of the air springs and large casting structures, it is difficult to access the articulation centre with the laminated cone for routine maintenance visual inspections. In order to overcome these restrictions and difficulties, it was decided to simply the design while retaining all the functions of the original articulation and to establish a more convenient maintenance scheme.
We have therefore studied all the principles and requirements for an articulated structure and derived all the necessary parameters to compile a list of possible design solutions for the new articulation as follows:

- **Articulation type**: Vertical/Horizontal joint / Ball bearing and Rotating assembly

- **Intermediate frame between cars**: Portal with z-link guidance / Portal with monolink guidance / Without intermediate frame

- **Bogie/carbody longitudinal interface**: king-pin and z-link connection / traction rod / king-pin and monolink

- **Bogie position & secondary suspension**: 2 air springs beneath articulation / 4 air springs beneath articulation / 2 air springs besides articulation

- **Yaw damper arrangement**: the combinations of 2 or 4 dampers between bogie to body / none or 2 dampers between body to body near bogie

- **Bogie-body dampers nearby the roof**: none / 2 dampers.

The advantages and disadvantages of each design solution were evaluated against the specified design requirements and parameters. The governing parameters and selected solutions are compiled in the following table and illustrated in figure 1.

<table>
<thead>
<tr>
<th>Items</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. axle load</td>
<td>17 tons</td>
</tr>
<tr>
<td>gauge</td>
<td>1435mm</td>
</tr>
<tr>
<td>Bogie type</td>
<td>Bolsterless</td>
</tr>
<tr>
<td>Pri. Suspension</td>
<td>Radial arm</td>
</tr>
<tr>
<td>Sec. Suspension</td>
<td>4 air spring beneath articulation + 4 yaw dampers + 4 vertical dampers + anti-roll bar</td>
</tr>
<tr>
<td>Bogie-body connection</td>
<td>King-pin and z-link</td>
</tr>
<tr>
<td>Articulation type</td>
<td>Horizontal type with Spherical rubber joint</td>
</tr>
<tr>
<td>Intermediate frame</td>
<td>None</td>
</tr>
<tr>
<td>Body-body damper</td>
<td>2 dampers nearby bogie + 2 dampers nearby roof</td>
</tr>
</tbody>
</table>

Table 1. selected parameters for articulated structure and bogie

The new articulated structure has a compact spherical rubber joint to be applied to a direction to coincide with the width of car. Each car is supported by two air springs so that the weight of car does not affect the articulation more than in the existing design. Accordingly, the new articulation is smaller, simpler and can be easily inspected through a space between both air springs.

**Strength assessment**

The new bogie frame was analyzed and tested to UIC 515-4. The new articulated structure was evaluated against the requirements specified in the UIC566, UIC615-4 and EN12663.
For the bogie frame, the static analysis revealed a maximum principal stress of 284.2 N/mm² against a yield strength of 325 N/mm². The fatigue loads were applied to the bogie frame for 10 millions cycles and no crack appeared. Furthermore, a complete articulation including the spherical rubber joint was also subjected to static load tests and dynamic tests for 4 millions cycles. For the static tests, a maximum stress of 378 N/mm² was recorded against a yield strength of 414 N/mm². After the dynamic test, the articulation did not exhibit any fatigue damage.

Dynamic assessment

A train with new articulated structures and new bogies was analyzed according to the UIC 518 method using the widely used simulation tool “SIMPACK”. The model represents a train composed of 8 passenger cars as follows (Figure 2):

![Figure 2. A train model for Dynamic analysis](image)

The model is symmetrical about the center line between bogie no. 4 and no. 5. The bogies are numbered from left to right as shown in the figure 2. In the model, the suspension arrangement of each bogie follows the parameters specified on table 1. Wheels with a 1/40 profile to NFF01112 as generally used for high speed trains are included in the model. Also, in Korea, the high speed lines have a UIC 60 rail with a 1/20 of rail inclination. When we can see the profile combination, it seems to have no equivalent conicity nearly shown in Figure 3.

![Figure 3. Equivalent conicity](image)

As a track irregularity, The German Railway (DB) ERRI LOW profile supplied in SIMPACK software was selected and applied in the dynamic analysis. It is a general irregularity provided in SIMPACK software and more severe than the high speed line in Korea. With the model and equivalent conicity, we have investigated the safety of the guiding force (ΣY₂m), the Y/Q ratio and the instability according to UIC 518 under the tare (W₀) and fully laden (W₂) weight conditions. The results are shown in figure 4 which illustrates the results for the front wheelset of each bogie from bogie no. 8 to 1. In tare and fully laden conditions, the guiding forces, the Y/Q ratio and the instability of each bogie are within the limits. Even though bogie no. 8 is a leading bogie, the Y/Q ratio and the guiding force are relatively lower than the others. The weight is a factor. Each car model has a different weight due to the numbers of passengers or the equipments arrangement. Bogie no. 8 is relatively heavier than the others. Accordingly, we can see such a result in the following figure;

![Graph 1](image)  ![Graph 2](image)
Field test

We have manufactured a new articulated structure and a new bogie as described in figure 1. In order to verify their performance, they were inserted in the existing HSR-350X high speed train which had already achieved a speed of over 352km/h in previous testing stages. The train consists of 7 cars including 2 power cars as shown in figure 5. On the train, the interface between TT4 and TM5 was reconstructed to fit the new articulated structure and the new bogie no.4. The new articulated structure was used to replace the existing articulation between TT4 and TM5. Figure 6 gives an overview of the modification.

To evaluate the performance of the new articulated structure including the new bogie on track, the simplified method described in the UIC 518 leaflet was used. Therefore, acceleration sensors were installed on the bogie frame and floor of the carbody. The accelerations were recorded on tangent track sections about 20 km long each along the main Korean high speed line. The average test running speed was about 300 km/h.
Figure 7 describes the lateral accelerations results for the bogie frame and the carbody for the safety requirements. Types no. 1 and 2 in figure 7 are results for the existing which had been already measured prior to the modification. Types no. 3 and 4 are results for the new bogie after replacement. We can see that the lateral accelerations on the bogie frame of both bogies are below the criteria of 10.44 m/s². However, it seems that the new bogie with lower lateral acceleration is better than the existing design. The lateral accelerations of carbody however are similar as shown in figure 7. This is assumed to be due to the influence of constraints such as dampers between bogie and carbody. An articulated train rely on inter-car articulated structure and dampers between bogie and carbody. The new bogie has two yaw dampers per bogie side frame. This gives more constraints than the existing bogie which has only one yaw damper per bogie side frame.

With regards to bogie instability due to lateral acceleration, all results also satisfy the criteria of 5.22 m/s² as shown in figure 8. However, the acceleration of the existing design is a little higher than the new bogie. It can be concluded that this is also due to the constraints arrangement.

Conclusion
In order to improve the structure and maintainability of the existing articulation, a new horizontal type of articulated structure was designed. Accordingly a new bogie was developed to adopt the
new horizontal articulated structure. The new articulated structure and bogie have been designed using strength and dynamic analysis of a whole train. And their performance has been evaluated through field testing. The newly developed articulated structure and bogie can be summarized as follows;

- An horizontal articulated structure type was developed. A new bogie to adopt this new articulated structure was also designed accordingly.

- The new articulated structure and bogie were evaluated through field testing. And the measured results satisfy the criteria for lateral accelerations on the bogie frame and instability in accordance with UIC 518. It means that the new articulated structure and the bogie comply with both the safety and stability requirements.

- The results for the lateral acceleration on the bogie frame show that the existing bogie has much higher acceleration than the new bogie. It is presumed to be due to the influence of constraints such as dampers between bogie and carbody.

- To quantify the influence of the constraints additional studies are required.

References