Development of a Customized Heavy Haul Bogie Design

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Summary: Heavy haul railway operations around the world are dependent upon properly designed and manufactured components, and the running gear of freight wagons is of critical importance for efficient and safe railway operations. This paper describes extensive efforts by a leading railway component manufacturer to design and manufacture a new heavy haul bogie “system” for the Indian Railways, who are entering the heavy haul arena. The paper outlines the many requirements of the design project including that: the bogie must be “track friendly,” must operate on broad gauge track (1676 mm), must perform satisfactorily at speeds up to 125 kilometers per hour, and that the bogie eventually must allow for operations at axle loads up to 32.5 metric tons. History of the existing Indian Railways CASNUB bogie is discussed along with historical applications of the Swing Motion style bogie utilized around the world. Dynamic modeling results for the new Indian Swing Motion bogie running on Indian track are presented. Additionally, service performance implications, including reduced wheel wear and reduced vertical and lateral forces, are discussed. Finally, upcoming oscillation trials of this new Indian Swing Motion Bogie on Indian Railways running lines are described.

1. INTRODUCTION

The Indian Swing Motion Bogie (Figure 1) was developed in response to Indian Railway’s need for a high speed heavy haul bogie to increase rail freight hauling capacity. The Indian Swing Motion Bogie was designed and developed by Amsted Rail Company per Indian Railways specification WD-45-MISC-2006 (Rev.1). The Indian Railways specification required the bogie to be capable of operating at a minimum of 25 tonne axle loads up to 32.5 tonne axle loads by only changing the spring suspension and the braking components. Because of the proven worldwide heavy haul service of the Swing Motion design, this bogie was chosen as the best bogie design for the new Indian heavy haul service. The Indian version of the Swing Motion Bogie was developed as a complete bogie system by Amsted Rail. The bogie castings and suspension along with the bearings, wheels, axles, and brake system were all designed for use together by Amsted Rail for this unique Indian application. Design Reviews have been conducted in association with Indian Railway’s to ensure that the bogie met all design aspects of the specification. Dynamic performance comparisons were made between the Indian Swing Motion Bogie running at 25 and 32.5 tonne axle loads and the existing Indian CASNUB 22HS bogie used in 22.9 tonne axle load service. Oscillation trials will be conducted in India to validate the Indian Swing Motion Bogie meets the performance requirements of the specification.

![Figure 1: Indian Swing Motion Bogie](image-url)
2. INDIAN CASNUB HISTORY

In 1980, RDSO introduced the BOXN wagon design, which included air brakes, the CASNUB bogie, TBU roller bearings, and CBC couplers. The axle load for the BOXN wagon was 20.32 tonnes. The original design was the CASNUB 22W which featured wide pedestals and roller side bearings. This design can be considered an enhanced three-piece truck design. It has cast side frame and bolster members with a friction damping system and secondary spring suspension. Squaring is enhanced with the addition of a mild steel spring plank which connects the side frames. Since 1980, the CASNUB bogie has gone through many design enhancements. The CASNUB 22 W (Retrofitted) was introduced to address shortcomings in the original design, especially wheel wear. Upgrades included elastomeric pads at the adapter/pedestal interface and elastomeric constant contact side bearings.

The next design iteration was the CASNUB 22NL and shortly thereafter the CASNUB 22 NLB. This design incorporated the narrow pedestal as well as the integral sliding brake beam pocket in the side frame. The B designation was added for a redesigned “fish belly” bolster to reduce the bogie weight. Finally, the current CASNUB 22HS was introduced. This is the current design used today by Indian Railways. Maximum speed was increased to 100 KMPH and the axle load was increased to 22.9 tonnes. A steel spring constant contact side bearing was incorporated as well as more load coil springs to handle the additional payload.

This design evolution has allowed the Indian Railways to increase ”per rake throughput”. The original BOXN design with the CASNUB 22W has a capacity of handling 3369 tonnes of lading per rake. With the introduction of the BOXNHNL utilizing the CASNUB 22HS, the throughput capacity has increased to 4118 tonnes. Rake size was also decreased by one wagon from 59 to 58 as the wagon length was increased by 250mm. The Indian Swing Motion Bogie at 25 tonne axle loads will allow the next generation of wagon, the BOXN25, to provide 4466 tonnes of throughput per rake, a 32.6% increase from the original BOXN design.

The development of the Dedicated Freight Corridors in India, has led to the need for a new bogie to operate at 25 tonne axle loads, with a future objective of increasing axle loads to 32.5 tonnes, the current standard in North America. The DFC program will provide upgrading of transportation technology, increases in productivity and reduction in unit transportation costs. The surging power needs requiring heavy coal movement, booming infrastructure construction, and growing international trade by India have led to this need. Coupled with saturation on some of the main operating lines, new infrastructure can be most cost effective coupled with improved rolling stock for higher throughput and efficiency. This led to the issuance of Indian Railways tender: GLOBAL TENDER NO: 2007/ DEV. CELL/ IGR/1, FOR PROCUREMENT OF HEAVY HAUL TRACK FRIENDLY BOGIE. The bogie described in this paper is the result of a complete system design to meet these tender requirements.

3. ANALYSIS OF INDIAN RAILWAYS BOGIE TENDER REQUIREMENTS

The Indian Railways specification WD-45-MISC-2006 (Rev.1) outlined the parameters for the development of a heavy haul bogie for India. The heavy haul bogie was required to be “track friendly” and be able to be used for variable service loads, beginning with 25 tonne loads and peaking at 32.5 tonne axle loads. The lateral dynamic performance characteristics of the bogie were emphasized in the specification and were the main driver for the chosen bogie design. The specification referenced a bogie that would have low dynamic forces, low wheel wear, and have reduced maintenance cycles even at track speeds of 110 KMPH. Other requirements of the specification included:

- Cast 965mm diameter multiple wear wheel with Indian Railways profile
- Side frame and bolster castings designed to meet AAR strength requirements for 32.5 tonne axle load
- 5.2 tonne complete bogie weight target
- AAR Class M Roller Bearings
- Broad gauge axle
- Bogie mounted brake system

Based on the emphasis of “track friendliness” in the specification, Amsted Rail determined that the Swing Motion Bogie system would be the optimal choice for this heavy haul application, and subsequently submitted this design in response to the Global Tender. After the normal review process for Global Tender’s, Amsted Rail was notified that its tender was selected as the final candidate.

The ability for the side frames to “swing” relative to the wheel sets and bolster allows for improved lateral stability and decreased lateral wheel forces on the rail. The reduced lateral forces and increased lateral stability allows for reduced wheel wear and reduced maintenance on the bogie and rail infrastructure.

The Indian Swing Motion Bogie side frame and bolster castings were designed as variations of existing Swing Motion Bogie castings produced for North America. The side frame was developed to accommodate the 965mm diameter wheel, class M bearing, and to fit within the clearance diagram provided in the specification. The bolster was designed for the 1676mm broad gauge track and to utilize bogie mounted brakes. Both the side frame and bolster castings were designed using Amsted Rail’s patented one-piece core technology to provide the
lightest weight castings possible. The bogie specification targeted a complete bogie weight of 5.2 tonnes including wheel sets and brake components. In order to achieve this very aggressive weight target, the side frame and bolster castings were designed with finite element analysis to optimize their respective weights while maintaining the 32.5 tonne capacity.

The 965mm multiple wear cast wheel was also a new design created for the Indian Swing Motion Bogie. Indian Railways has been utilizing 1000mm multiple wear wheels on the CASNUB bogie design. The 965mm multiple wear curved plate wheel was designed and developed by Amsted Rail and manufactured by their pressure poured casting process. The wheel was designed to provide the strength needed for the 32.5 tonne service but also kept in mind the weight target for the bogie. A Class M bearing and corresponding broad gauge axle were also developed for the Indian Swing Motion bogie system along with a new broad gauge bogie mounted brake system.

4. SWING MOTION BOGIE APPLICATION AND DESIGN HISTORY

The Swing Motion style bogie has been used all over the world where high performance and low maintenance is required at higher track speeds. The lateral dynamic performance of the Swing Motion Bogie in high speed applications is the key to protecting the lading and wagon body from high lateral forces and accelerations which cause damage and wear. There are over 50,000 wagon sets of Swing Motion bogies currently in service in North America and over 30,000 wagon sets in China. In North America, the Swing Motion bogie is used extensively in autorack service where lading damage is a concern. In China, the Swing Motion Bogie has been primarily used on gondola wagons. The Swing Motion Bogie was chosen in China because of the ability to increase axle loads and increase speed which ultimately increases freight hauling capacity.

The Swing Motion Bogie design was initially developed in the 1970's to allow railroads to operate at higher speeds without reducing ride quality. The Swing Motion bogie provides a cost effective means for providing safe, high speed capability while reducing rolling stock and track maintenance. Multiple field studies from North American heavy haul service have shown the capability of the Swing Motion Bogie to achieve over 1.6 million kilometers of service before needing any bogie maintenance.

5. SWING MOTION BOGIE DESIGN FEATURES

The Swing Motion Bogie is an enhanced three-piece truck (Figure 2) that adds a spring plank member (transom) between the side frames and includes pivot points at both the side frame pedestal and the side frame spring seat. This patented design allows the side frames to function as a spring hanger, providing lateral decoupling between the rail/wheel lateral inputs and the wagon body. This design results in a low resistive force against the lateral displacement of the bogie bolster. When the lateral displacement forces exceed this low resistive force, the second stage of operation takes over. The "swing mechanism" allows the bogie side frame to move laterally. This provides greater stability and hunting free performance at higher speeds.

Figure 2: Exploded View of Indian Swing Motion Bogie
In addition, the Swing Motion design provides for improved roll control and stability. Unlike a conventional three-piece bogie, lateral forces are transmitted below the axle, thus reducing the overturning moment, which minimizes wheel lifting and derailment potential (Figure 3).

6. DYNAMIC MODELING RESULTS

The Indian Swing Motion Bogie was evaluated per specification requirements in a dynamic simulation utilizing both Vampire and NUCARS modeling software. The simulations compared the performance of the Indian Swing Motion Bogie to the existing Indian CASNUB bogie. The Indian Swing Motion Bogie demonstrated excellent performance by reducing the lateral forces on the rail as compared to the CASNUB bogie. The vertical performance was also an improvement over the CASNUB bogie even though the lading loads on the Indian Swing Motion Bogie were significantly higher than on the CASNUB bogie.

Performance trend lines were generated from the dynamic simulation for comparing the new Indian Swing Motion Bogie and the CASNUB bogie. The CASNUB bogie was analyzed on a 22.9 tonne per axle coal wagon while the Indian Swing Motion Bogie was analyzed on a 25 tonne per axle coal wagon and two variations of a 25 tonne per axle container flat wagon. At higher speeds, the Indian Swing Motion Bogie had lower forces on the rail and lower accelerations for both the wagon body and the bogie. Figures 4 and 5 compare the vertical accelerations in both the straight and curved track sections for the 25 tonne per axle wagons equipped with the Indian Swing Motion Bogie to the 22.9 tonne per axle wagon equipped with the CASNUB bogie. The trend lines show that as speed increases the vertical performance of the Indian Swing Motion Bogie is improved over the CASNUB bogie in the loaded condition.

The dynamic simulations also predicted that the lateral forces and accelerations would be lower for the Indian Swing Motion Bogie. Figures 6 and 7 demonstrate the lateral accelerations and forces for the empty wagon on the straight section of track.

![Figure 3: Center of Rotation Diagram](image-url)

6.1. Vertical Accelerations (Straight)

Figure 4: Vertical Accelerations (Straight)

6.2. Vertical Accelerations (Curved)

Figure 5: Vertical Accelerations (Curved)

6.3. Lateral Accelerations (Straight)

Figure 6: Lateral Accelerations (Straight)

6.4. Lateral Forces (Straight)

Figure 7: Lateral Forces (Straight)
The Indian Swing Motion Bogie also provides the lateral force and acceleration benefit in curves for the empty wagon (Figures 8 and 9). At the higher speeds above 80 KMPH, the CASNUB bogie lateral forces and accelerations tend to be higher than the Indian Swing Motion Bogie. The lower lateral forces and accelerations of the Indian Swing Motion Bogie provide for reduced wheel, track, and bogie wear.

Another significant parameter for examining overall performance of a bogie and wagon combination is the measurement of the lateral wheel force divided by the vertical wheel force commonly referred to as the "derailment coefficient". This Y/Q or L/V value gives a good indication of the overall tendency of the bogie wheel to climb the rail. When the vertical force on a single wheel is low and the lateral force is high, the wheel tends to move laterally and can climb the rail. Values under 1.0 are considered to be safe from a derailment point of view. The Swing Motion design allows for low lateral forces and has the ability to keep the wheels from unloading. This dynamic combination provides low Y/Q or L/V values throughout the speed range. Figure 11 demonstrates the Indian Swing Motion Bogie compared to the CASNUB bogie for values of L/V. The general tendency is for the Indian Swing Motion Bogie to have lower L/V values than the CASNUB bogie. The L/V values in the curved section of track show similar low values for both the Indian Swing Motion Bogie and the CASNUB bogie (Figure 12).

The lateral performance of the Indian Swing Motion Bogie is significantly better than the CASNUB bogie as well for the loaded wagons on straight track. The lateral wheel forces on the Indian Swing Motion Bogie were lower than the CASNUB bogie at all speeds for the loaded wagons (Figure 10). These lower wheel forces in the loaded condition significantly improve wheel wear and reduce flange wear on the wheels.

Another significant parameter for examining overall performance of a bogie and wagon combination is the measurement of the lateral wheel force divided by the vertical wheel force commonly referred to as the "derailment coefficient". This Y/Q or L/V value gives a good indication of the overall tendency of the bogie wheel to climb the rail. When the vertical force on a single wheel is low and the lateral force is high, the wheel tends to move laterally and can climb the rail. Values under 1.0 are considered to be safe from a derailment point of view. The Swing Motion design allows for low lateral forces and has the ability to keep the wheels from unloading. This dynamic combination provides low Y/Q or L/V values throughout the speed range. Figure 11 demonstrates the Indian Swing Motion Bogie compared to the CASNUB bogie for values of L/V. The general tendency is for the Indian Swing Motion Bogie to have lower L/V values than the CASNUB bogie. The L/V values in the curved section of track show similar low values for both the Indian Swing Motion Bogie and the CASNUB bogie (Figure 12).

Oscillation trials will be conducted in India to verify that the Indian Swing Motion Bogie meets the performance criteria outlined in the specification. These oscillation trials will use instrumented wheelsets to measure vertical and lateral forces. In addition to the instrumented wheelset, the trailing bogie will be instrumented for
registering: vertical and lateral accelerations on the floor above the center pivot, dynamic spring deflections, bogie rotation, bolster swing and roll of the wagon body as well as roll travel of the constant contact side bearings. The test consist will include a locomotive, an instrumentation car, and the test wagon. The trials will be conducted on both a double stack container flat wagon and a coal wagon specifically designed and built for 25 tonne axle loads (Figure 13). Measurements will be made in both the empty and loaded condition for speeds ranging from 60 KMPH to 125 KMPH. The oscillation trial test section beginning in Kota, India includes both tangent track and two degree curves and a station section with points and crossings. The Indian Swing Motion Bogie and new 25 tonne per axle wagons will also be tested on Indian Railways revenue track in Palanpur.

8. CONCLUSION:
The Indian Swing Motion Bogie was designed and manufactured as a complete system to meet the heavy haul needs of the Indian rail market. All components were designed to meet the required 32.5 tonne axle load requirements and to be as light weight as possible. The dynamic modeling demonstrates that the Indian Swing Motion Bogie will meet the requirements of the Indian Railways specification and will also be an improvement over the existing Indian CASNUB bogie currently in use today. Oscillation trials are scheduled to begin in September 2012. These trials will include speed certification of both empty and loaded coal and container flat wagons. The Indian Railways assessment criteria for the oscillation trials are shown in Figure 14.

It is expected that oscillation trial data will be available before the presentation of this paper in February 2013. The paper and presentation will be updated with any new information resulting from these oscillation trials.

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<th>S. No.</th>
<th>Parameter</th>
<th>Values</th>
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<td>Derailment Coefficient (Max.)</td>
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<tr>
<td>2</td>
<td>Lateral/transverse force lasting more than 2m (Hy2m) (tonnes). Prud'homme Limit = [0.85 (1+P/3)] where P = Axle load in tonnes.</td>
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<tr>
<td>8</td>
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Figure 14: Indian Railways Assessment Criteria

Figure 15: BOXN25 Wagon with Indian Swing Motion Bogies