Design of railway bogies in compliance with new EN 13749 European standard

Giampaolo Mancini[1], Alessandro Cera[1]

[1] *FS Trenitalia, DISQS, Ingegneria di Base e Ricerca, Firenze, Italia*

Abstract

As a consequence of the standardization process developing in Europe, on April 2005 the new European standard EN 13749 was issued by the European standardization body CEN. The aim of the norm is to define the complete design process of new railway bogies. It includes design procedures, assessment methods, verification and manufacturing quality requirements. In the paper all the main aspects of the norm are described focusing the acceptance process of new railway bogies.

The EN13749 norm codifies static and fatigue load assumptions, as well as calculations and test methods to verify the static and fatigue resistance of the bogie frames. An item not deepened in the norm is the methodology to evaluate the fatigue strength by means of calculations. In the paper fatigue analysis is investigated comparing two different approaches (endurance limit and Goodman diagram) and different calculation methodologies.

Finally, the procedure to validate the design process is described comparing the results of fatigue calculations and fatigue tests for a Hembot bogie.

1. Introduction

So far, the design process for a new railway bogie frame has been carried out according to the UIC leaflets for on-bench tests (UIC 515-4 for trailer bogies, UIC 615-4 for motor bogies, UIC 510-3 for freight application bogie). Moreover the unavailability of validated calculation instruments did not enable to investigate in detail the structural behaviour of the frame. The manufacturer experiences and the conformity to the static and fatigue test to UIC Leaflets were considered enough to approve bogie frame structural resistance. With the improving of new numerical calculation codes (Finite Element Method) the standardization of all phases of the design process of the bogie frame has been possible.

The norm EN 13749 standardizes and develops the requirements already present in the UIC leaflets for test verifications and defines all the technical requirements for the acceptance process in order to achieve a complete satisfactory design of the bogie, including axle boxes housings and the bolsters on the frame.

In this standard, a path to verify the whole project is defined. Starting up from a check on its geometric features (delivery of the preliminary drawings), every step of the verification procedure leads to the achievement of the technical approval. So, the aim of this new standard is to assess the validity of the design choices done by the manufacturer for a new bogie frame.

2. Technical specification: a customer responsibility

The first step of the design process is the definition of the responsibilities of supplier and customer in the design and fabrication of a new railway bogies. Customer responsibility is to provide to the bogie supplier a technical specification with all the requirements necessary for the bogie design (technical and operational characteristics, performances, interfaces with components and assemblies, reference standards and other technical specification, functional requirement, environmental conditions, etc). Therefore the customer shall specify all the information necessary to the supplier to design the bogie. Moreover the customer has also to specify:

- the classification of the bogie type within the categories specified by the norm;
- the delivery of all the documentation necessary for the design approval (drawings, specifies, calculations, type test reports);
- a planning of the activities for the design approval (all activities which are necessary to demonstrate that the design meet the conditions defined in the technical specification and the requirements in the norm).
- the delivery of a quality plan which shall be used to manufacture the bogies and shall identify a quality control process aligned with the status of the art.

3. Acceptance programme: a supplier responsibility

The design of the bogie frame shall be carried out by the supplier following the acceptance procedure defined in the norm. The activities in the procedure shall demonstrate that the design of the bogie fulfils the conditions defined in the technical specifications and that the behaviour of the bogie frame will be acceptable in service without the occurrence of defects such as ruptures, permanent deformations and fatigue cracks.

The steps of acceptance programme for a new bogie frame, identifying the complete design process, are the following:

- structural calculations for static assessment;
- structural calculations for fatigue assessment;
- static tests;
- fatigue test;
- on-track tests.

The load combinations defined in the norm correspond to the typical load conditions for all the specified categories of bogies, in normal operations as well as in exceptional condition operations.

A reduced programme could be accepted in case of an existing design of bogie frame used for new application, or a modification of an existing design.

4. Calculations

4.1 General methodology

The aim of the calculation process is to verify that no permanent deformations or fatigue failures occur in the specified life of the new bogie frame.

As regards the calculation process, the structural analysis is divided in two phases:

- structural analysis of the bogie frame by FEM calculations;
- structural analysis of the attachments components-bogie frame by FEM calculations.

On each phase two different structural verification are required:

- static calculation with the exceptional load cases representing extreme loads that might occur only rarely during the life of the bogie;
- fatigue calculation with normal service load cases, representing those loads that can occur during normal operations.

For the two verifications above the calculation process for the acceptance procedure requires the following activities:

- determination of the forces that occur in the interfaces of the structure
- combination of these forces in load cases representing operation conditions
- analysis of the stress values caused by the application of every load cases
- assessment of the calculated stress values comparing them to the acceptable stress limits.

4.2 Bogie frame calculations

4.2.1 Loads on the bogie frame

During bogie lifetime several external forces, both exceptional and normal service loads, act on the bogie frame, coming from the wheel-rail contact points and from the interfaces with the carbody. These forces are generated from:

- double sprung masses, including payload;
- track irregularities;
- lateral accelerations caused by curve riding;
- longitudinal accelerations caused by traction and braking;

as well as other typically exceptional events, for instance:

- exceptional pay-loads;
- buffer impacts;
- minor derailments.

Taking into account all the above listed sources the norm defines formulas and coefficients to evaluate the values of the single forces to apply in the calculation process. Groups of these forces, combined in load cases, allow to simulate the majority of static and fatigue stress condition on the bogie frame when it is operated on the reference vehicle.

4.2.2 Static calculation with exceptional loads

The aim of the static calculation with exceptional load is to verify that the ratio between the yield stress (or proportional limit stress $R_{0,2\%}$) and the Von Mises stress in the whole structure is higher than 1 for the complete acceptance program or than 1.5 for the reduced program.
The forces to apply for the static calculation with exceptional loads are:

- *vertical forces coming from sprung masses*
  For the typical passenger and locomotive applications (categories B-I, B-II and B-VII) the loads produced by a vertical acceleration of 1.4 g on the sprung masses (including the exceptional payload) shall be directly applied on the interfaces between bogie frame and secondary suspension. For freight applications (categories B-V) different values and application points have to be considered as a consequence of different geometries of the connection between bogies and wagon frame.
- *transversal forces coming from each axle*
  These forces are generated by wheel-rail contact forces in curve riding. The formula in the norm takes into consideration the Proud'Homme limit for the sum of the lateral forces and it is the same for all the categories of railway bogies. In the numerical calculations the constraints are normally applied on the axles and the loads on the bogie-car body interface, putting attention to replicate the load scheme of this connection (e.g. in some applications a central pivot is present).
- *longitudinal forces*
  Longitudinal exceptional forces are caused from exceptional vertical loads and curve riding.
- *forces of a potential collision*
  A longitudinal impact of a wagon weighing 80 t at the speed of 10 km/h shall be examined applying a longitudinal acceleration equal to 5 g to the bogie masses for trailer vehicles and 3 g for motor bogies. These loads generate normally the most severe stress state on the longitudinal connection between bogie and carbody.
- *track twist*
  As regard the loads caused by track twist the standard defines different load combinations and values depending on bogie categories. For trailer bogie (passenger as well as freight) two load condition shall be evaluated: a track twist 1% and a complete unloading of a wheel. This last condition simulates a low speed derailment. In case of motor bogie of locomotives (categories B-VII) only the first load condition is required.

For calculations with static exceptional load all the above forces are combined in 4 load cases:

- load case 1: vertical forces + transversal forces + 1% track twist
- load case 2: vertical forces + longitudinal forces
- load case 3: potential collision (5 g or 3 g applied to bogie mass)
- load case 4: complete unloading of a wheel with empty vehicle

Figure 1 shows an example of the application of the four load cases.

	Load case 1	Load case 2	Load case 3	Load case 4
F_Z on the side frame	✓	✓	✓	✓ (*)
F_Y	✓			
F_X on the wheel		✓		
Longitudinal collision			✓	
Track twist	✓			
Unloading of one wheel				✓

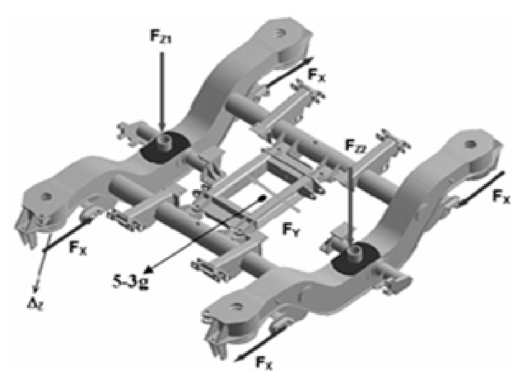


Figure 1 – Load cases for static calculation with exceptional loads

4.2.3 Fatigue calculation with normal service loads.

The forces to apply for fatigue calculation are:

- *vertical forces coming from sprung masses*
  According the norm three components are present in these forces:
  - a static component coming from the sprung masses (with normal service payload) ;
  - a quasi-static component taking account the carbody rolling motion in curve riding; its amplitude is conventionally calculated as a percentage of the static component (roll coefficient α);
  - a dynamic component connected to carbody vertical acceleration in curve riding; its amplitude is conventionally calculated as a percentage of the static component (by means of a bounce coefficient β);
- *transversal forces coming from each axle*
  For all bogie categories the transversal forces are the inertial forces caused by curve riding and by track defects. According to the norm two components are present in these forces:
  - a quasi static component equal to 0.063 g due to non compensated acceleration ;
  - a dynamic component equal to 0.063 g due to track irregularities.
- *longitudinal forces:*
  Longitudinal forces are caused from sliding between wheel and rail connected with yaw motion on straight track and with the radius difference of the rolling circle on curves.
- *track twist*
  A conventional track twist 0,5% shall be calculated in order to take into account the effects of typical twists of bogie in curve transitions.

An example of load combinations for passenger and locomotive applications is shown in figure 2. In this case vertical, transversal and track twist forces have to be combined on 9 load cases. Moreover, the norm defines other two load cases adding longitudinal forces to vertical forces. According the norm, these load cases take into account all the possible load configurations in normal operations.
The fatigue calculation requires the evaluation of stresses for every load cases and the analysis of the fatigue cycle characteristics on all the bogie frame in order to check the fatigue resistance.
The two different approaches proposed by the norm with their benefits and disadvantages are described below. It is essential to notice that the choice of the method for fatigue analysis has to be agreed between customer and supplier or clearly required from the customer in the technical specification.

- *Endurance limit*
  It's the method mainly used utilized since the issuing of UIC leaflets and it is used also for the analysis of fatigue static tests (afterwards described). In this method the maximum and minimum stress values σ_{max} and σ_{min} generated by the all load cases separately applied are determined on each point of the bogie frame. These values allow to define the mean stress σ_m and the fatigue cycle amplitude to compare with the fatigue limit of the material (using for example the Goodman diagram).
  This method is generally conservative and does not require the knowledge of load spectrums applied on the bogie in its lifetime. A major advantage of the method is that the fatigue limits for the typical steels used for bogies are very well known for the basic material as well as for the majority of welded joints, also in case of not heat treated bogies (the report ERRI B12 RP 60 gives all the fatigue data and the Goodman diagrams). A disadvantage of the method is the rough simplification carried out on the real load spectrum applied on the bogie.

- *Cumulative damage*
  According to this method all the effects due to the combinations of load cases are considered. The estimated number of cycles applied on the bogie for each load cases is the data which is necessary to know and which is used to verify the fatigue resistance by means of the Wohler diagram (S-N) of the material. Then, in agreement with a hypothesis for damage accumulation (for example Palmgren-Miner rule), the total damage can be determined.
  The use of load spectra close to reality is the main advantages of the method allowing to optimise structural strength and weight of the bogie frame. At the same time the definition a n load spectrum taking into account all the operative condition is a very complex item to perform.

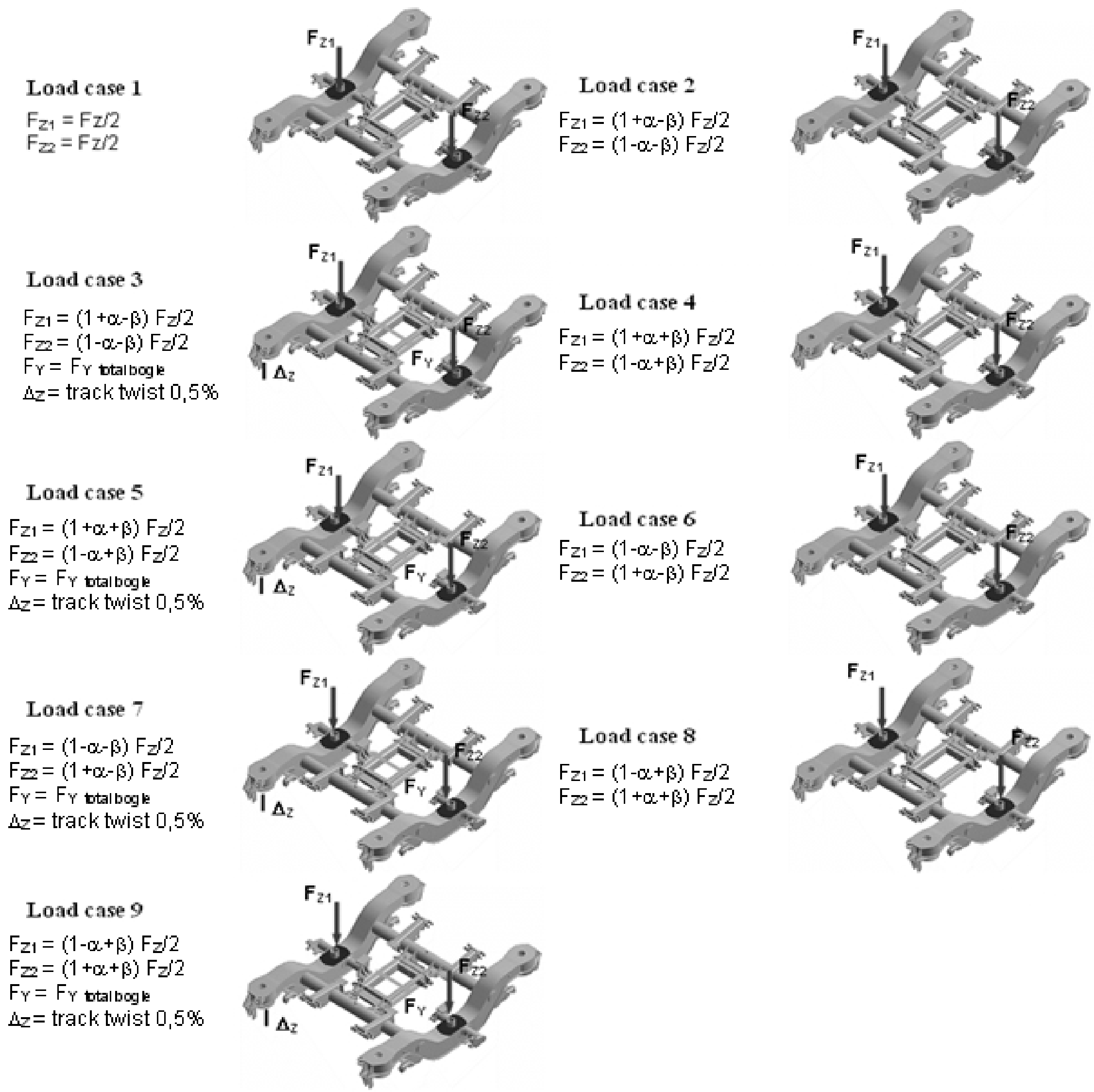


Figure 2 – Load cases for fatigue calculation of passenger and locomotive bogie frames

4.3 Frame attachments calculation

During bogie lifetime both operative and inertial loads act on the attachments to the bogie frame. For this reason a local structural calculation of these parts shall be done with the aim to demonstrate the structural strength of attachments both to exceptional and normal service loads.

For the static calculation with exceptional loads it shall be verified that the ratio between the yield stress value (or proportional limit stress $R_{0,2\%}$) and the Von Mises stress and in the whole structure is higher than 1 for the complete acceptance program and than 1.5 for the reduced acceptance program. The exceptional forces to apply on the attachments are:

- inertial forces due to the masses attached to the bogie frame;
- inertial forces due to the masses attached to the axle box (unsprung masses);
- exceptional loads resulting from dampers;
- exceptional loads resulting from braking;
- exceptional loads resulting from traction motor;
- exceptional load applied on anti-roll system;

These forces are combined all together or separately with the vertical maximum forces due to sprung masses.

For the fatigue calculation with normal service loads the same typology of forces used for the calculations related to exceptional loads are applied calculating them with the typical parameters of normal service. The fatigue calculation shall be carried out separately for every support. Two load cases for each calculation have to be performed:

- vertical loads (due to sprung masses) and maximum/minimum inertial service accelerations acting on the attachments;
- vertical load (due to sprung masses) and maximum/minimum operative forces acting on the attachments (due to dampers, braking, etc.).

The verification methods are the same described for the fatigue calculation of the bogie frame.

5. Static tests program

The next step of the acceptance programme is the verification on the static test rig. A bogie frame which is totally compliant with the design and coming from the same manufacturing process of the frames to use in operations shall be tested on a rig capable to replicate the same load cases verified in the calculation assessment.

The static test program has two main aims. The first aim is to verify that both for bogie frame and attachments these two requirements are met:

- the measured stress values coming from exceptional loads are lower than the static admissible stress (R_S or $R_{0,2\%}$);
- after the application of all the fatigue load cases required, on the whole structure (especially on the welded joints) the fatigue cycle characteristics shall not exceed the admissible fatigue limits; in this case the endurance limit approach is required in the norm.

The second aim is to validate the FEM calculation. To this purpose, in addition to the need to satisfy the requirements of the norm for the test program, it is necessary to apply the replicate on the test rig the same static and fatigue load cases used for the calculation's activities. It is necessary to notice that the norm does not define a limit for the difference between the calculated and the measured stress (or strain) on the bogie frame.

The test rig equipment is generally made by a rigid structure on which are assembled all the actuators and the devices necessary to produce loads and constraints. In order to reduce the complexity of the test, it is not necessary for the norm to include wheel-sets and real primary suspension springs. To this sake the way used to replicate loads and constraints on the primary suspension shall not modify significantly the structural behaviour of the bogie (compared with the real suspension). The load are normally applied on the vertical and lateral connections between bogie and car body, whereas the constraints are placed at the primary suspension level. One of the primary suspension shall be connected with a vertical actuator producing the loads due to track twist.

The tested bogie frame shall be equipped with the original axle box and the norm specifies that the tests is valid also for the design verification of this component.

6. Fatigue test program

The third step of the acceptance procedure of a new bogie frame is the fatigue test program on the rig. The conditions to satisfy for bogie frame in order to proceed with this test program are:

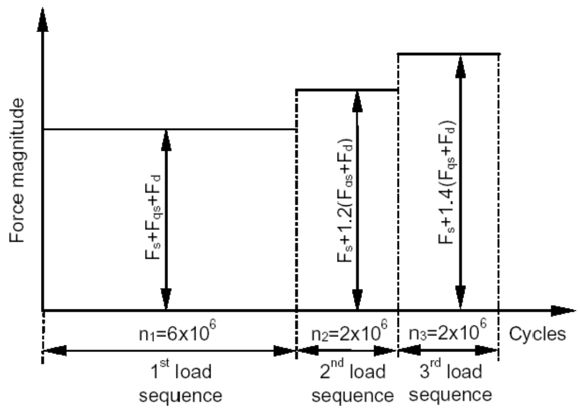
- it shall be compliant with the approved (from the customer) quality plan;
- it shall be equipped with original axle-box housing and bolsters;
- the system substituting the primary suspension system on the test-rig shall have stiffness characteristics similar to the real ones.

In the fatigue test program the same vertical, transversal and track twist loads used for the fatigue calculation are combined in a test programme applying 10 million of load cycles divided in three steps, as described in figure 3. In this figure the test rig used for Hembot bogie is also shown. In the first step the static, quasi-static, dynamic and track twist loads act for 6 million of cycle; in the second step the quasi-static, dynamic and track twist loads are increased 20% and act for 2 million of cycles; finally in the third steps the same loads are increased 40%.

As a matter of fact, on the fatigue test only loads caused by negotiating curves or switches are applied. Continuous passages from right to left curves are simulated alternating the versus of vertical and lateral quasi- static loads.

The fatigue test is passed if both the following requirements are met:

- no cracks are born at the end of the first two steps;
- at the end of the third step very small cracks are permitted, if their length in operation would not require immediate repair.



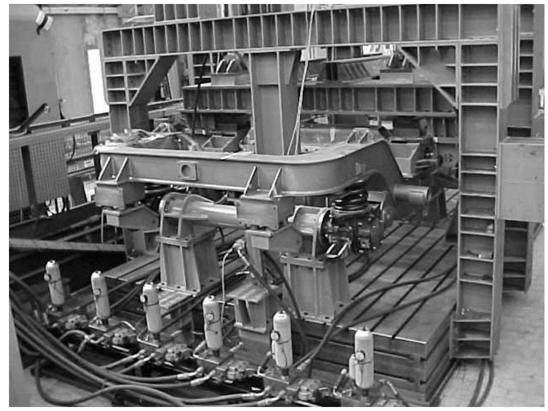


Figure 3 - Load sequence and equipment for fatigue test programme

7. On-track tests

At the end of the acceptance programme the on-track tests have the aim to measure the real stress values generated in operations and to verify that they are reasonably next to those calculated and measured on the test rig.
Generally on-track tests are required and carried out for bogi es with a large rate of innovati ve solutions. The norm permits to carry out a reduced test program or to use a simplified procedure in case of an existing bogie design used for a different application.

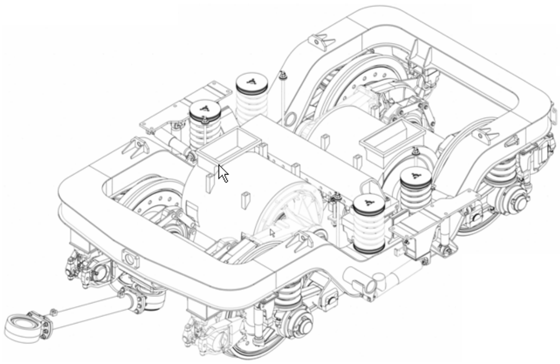
8. The open points of the norm

8.1 The methodology for multi-axial stress fatigue analysis as main open point

An essential point that is still open in the EN 13479 norm are design loads and parameters for tilting train bogies as well as the effect of the maximum non compensated acceleration in operations on the load values. This item is definitely not investigated in the norm.
However the main open point regards the methodology for fatigue analysis. Although guidelines and approach methods for the calculation process have been codified, the methodology for the analysis and evaluation of the multi-axial stress fatigue cycles (regarding actually the whole bogie frame) has not been deepened. Moreover the norm specifies that the methodology of combination and evaluation of the calculated stress values for fatigue analysis shall be defined in the customer technical specification or to be agreed between customer and supplier. This fact implies that a same bogie design from a structural point of view can be linked to different methodologies of fatigue analysis for different customers or suppliers. This is an open point of the norm which shall be solved in the next years to achieve a fully standardisation of the bogie design process, since the results of fatigue calculations and of static tests are directly connected with the methodology used for fatigue analysis.
The above consideration is valid independently from the fatigue approach selected between the two ones proposed in the norm (cumulative damage and endurance limit methods). In fact the input data of both methods are the characteristics of fatigue cycles (maximum stress value σ_{max}, minimum stress value σ_{min}, stress value amplitude $\Delta\sigma$ and mean stress value σ_m) which can be determined only by means of a multi-axial stress fatigue analysis.

8.2 Fatigue calculation of the Hembot bogie

A first examples of a methodolog y for the fatigue analysis of multi-axial stress is presented the for bogie frame calculation.
The FEM calculation of the Hembot motor bogie frame, carried out in compliance with the new EN13749 standard (at that time a project of norm), was developed from the Italian manufacture Ansaldobreda within the EU-funded research project named Hembot, including also FS Trenitalia. The calculation has been carried out c onsidering the bogie mounted on a Italian E402 locomotive. This locomotive was then equipped with two Hembot bogies and on-track tests were carried out within the research project to validate structural and dynamic behaviour of the bogie.
Figure 4 shows a 3-D drawing of the bogie and the main input parameters for the calculation.



- bogie category: B-VII
- rolling coefficient α= 0,1
- bouncing coefficient β = 0,2
- Loco E402B weight = 86277 kg
- Bogie weight = 15.260 kg
- Wheel base = 2750 mm
- materials:
  - frame: steel UNI EN 10025 S355J2G3C
  - central transom: aluminium AlMg4.5Mn EN AW-5083 W28
  - axle box: EN-AC-Al-Si-7Mg0,6

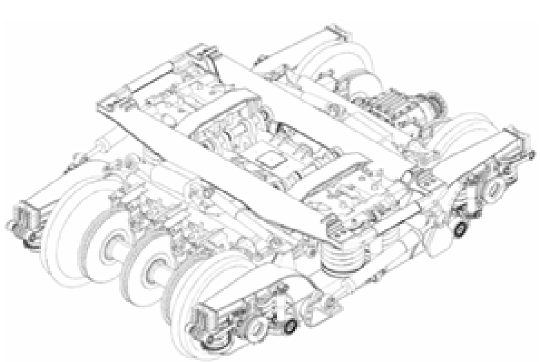
Figure 4 - Hembot bogie

Fatigue calculations have been performed with the method of cumulative damage and the sequence of loads specified in the standard for the fatigue test program has been used as load spectrum.
The methodology to analyse the stress values in order to evaluate the fatigue cycle characteristics and the safety factors is described below:

a. all the load cycles included in the load spectrum are identified;
b. for each load cycle the two extreme load cases are identified, that is the load case related the maximum load condition of the cycle and the load case related the minimum load condition of the cycle;
c. for each load case a FEM calculation is carried out;
d. for each load case on every element of the FEM model located on welded joints, a local coordinate system is considered: a x-axis in longitudinal direction (locally aligned whit the axis of the welding) and a y-axis for the transversal direction (normal to the axis of the welding);
e. an analysis of FEM calculations of the two extreme load cases is carried out to identify the tensile and shear stress values related to the above coordinate system in every element of the structure;
f. the parameters of three fatigue cycles are evaluated (maximum and minimum stress value, amplitude and mean value) to identify:
   - a longitudinal stress cycle $\Delta\sigma_{xx}$ (tensile-compressive stress cycle parallel to the welding);
   - a transversal stress cycle $\Delta\sigma_{yy}$ (tensile-compressive stress cycle normal to the welding);
   - a shear stress cycle $\Delta\tau_{xy}$ (tangential stress cycle in the longitudinal section of the welding).
g. considering the number of applications hypothesized for each load cycles, for every element of the welded joints the cumulative damage and relative safety factor is evaluated using an approach based on Miner's rule (and defined on the Italian standard CNR UNI 10011).

8.3 Fatigue calculation of the bogie of New Pendolino tilting train

The bogie frame design of the New Pendolino tilting train of Trenitalia has been developed from Alstom according to the acceptance programme defined in the standard EN 13749, even if the norm does not specify special parameters or requirements for tilting applications. For these reason, in order to validate the design, it is necessary to verify that the design loads correspond to the loads measured in operations.
The 3-D drawing of the bogie and the main input parameters of the calculations are shown in figure 5.



- bogie category: B-I
- roll coefficient α = 0,1
- bounce coefficient β = 0,2
- loco E402B weight = 58635 kg
- Bogie weight = 8430 kg
- exceptional payload = 10880 kg
- normal service payload = 8640 kg
- Wheel base = 2750 mm
- materials:
  - frame: steel UNI EN 10025 S355 J2 G3C
  - axle box housing: EN GJS 400-18-LT

Figure 5 - New Pendolino bogie

The fatigue analysis has been carried out applying the vertical, transversal and track twist load cases so as previously described.
The methodology to analyse the stress values in order to evaluate the fatigue cycle characteristics and the safety factors is described below:

a. for each load case a FEM calculation is carried out;
b. for all the calculated load cases on every node of the model the values of Von Mises equivalent stress, of the maximum principal stress and of the minimum principal stress are determined;
c. on every node the amplitude of the fatigue cycle is evaluated as the difference between the maximum and the minimum Von Mises stress values;
d. on every node the mean value of the fatigue cycle (without sign) is evaluated as mean value of maximum and minimum Von Mises stress value;
e. the sign of the principal stress value with higher absolute value is assigned to the mean value previously evaluated;
f. finally, on every node amplitude and mean value of the fatigue cycles are compared with the admissible limits of the Goodman diagram, according to the conditions defines in ERRI B12/17 report, so that that the safety factors can be evaluated.

8.4 Fatigue calculations within FS Trenitalia

The fatigue calculation methodology which has been consolidated in the latest years within the engineering department of FS Trenitalia can be described by the following main features:

- FEM calculations carried out with ANSYS 10 code;
- structural analysis of bogie frame and supports fully compliant to standard;
- analysis of multi-axial stress for fatigue according to ERRI B12/60 report;
- fatigue analysis by the endurance limit approach proposed in the EN13749 standard.

The methodology is applicable to all typologies of bogie frames and supports. It is important to notice these significant aspects:

1. the methodology can be totally related to existent and valid standards, from the definition load conditions to the evaluation of safety factors;
2. at the present state of the art of European normative the ERRI B12/60 report is the only technical document for bogie dealing with the fatigue analysis of multi-axial stresses;
3. the methodology to analyse multi-axial stress conditions and the admissible limit values defined in the ERRI B12/60 report is the result of an important co-operation in the fields of research on bogies among the major European railway companies, with the aim to integrate and standardise the existing methodologies concerning static and fatigue assessments and testing of bogie frame;
4. since the publication of the first drafts of EN13749, the European railway company SNCF, DB and FS decided together to include the requirements about the endurance limit approach and the ERRI B12/60 fatigue analysis in the common technical specification for HTE train project (High Speed Train for Europe) and then to transfer them also into the Modbogie project, a main part of Modtrain EU-funded large research project for the standardization of railway sub-system.

The main steps of methodology to evaluate the characteristics of the fatigue cycles and the safety factors are described below:

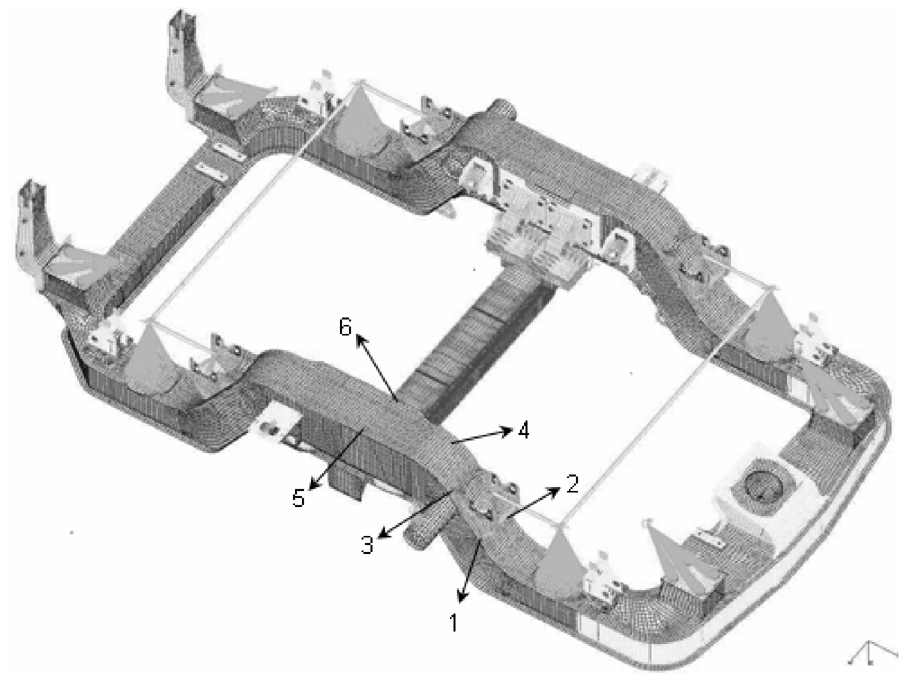
- for each combination of vertical, transversal and track twist loads a FEM calculation is carried out;
- stress tensors and principal stress values are identified for every node belonging to welded joints and to the areas of basic material with higher values of stress;
- on these nodes, considering all the load cases required by EN13749 norm (nine cases for passenger and locomotive bogies), the higher value among the principal stresses is defined σ_{max};
- the direction cosines related to σ_{max} direction are identified;
- in the same nodes the stress tensors of the other load cases are projected on the plane normal to σ_{max} directions;
- among all the calculated projections, the smaller one is defined $\sigma_{min;}$
- amplitude (σ_{max}-σ_{min}) and mean value (σ_{max}+σ_{min})/2 are compared whit the fatigue limits specified in the ERRI B12/60 report.

The same process is replicated for the other load cases taking into account the longitudinal forces on the bogie frame and also for the fatigue analysis of attachments.

9. An example of the validation phase of the calculation process

As an example of the validation process of calculation the Hembot bogie case is presented. Starting up from the results of FEM calculation and from the static tests carried out for the this bogie, a

verification of the values of calculated and measured strains has been performed. This activity has permitted to validate the results of the FEM calculation experimentally, as required by the acceptance procedure according EN13749 standard.
To this sake 88 strain gages were mounted on the bogie frame for the fatigue tests on the rig. The strain gage locations were selected in the areas with lower safety factors resulting from fatigue calculations. The aim of this work was to show a good agreement between the results of calculations and tests. As already noticed, the norm does not specify the admissible maximum difference and it was agreed in the technical specification at 20%.
Figure 6 shows the results of the comparative analysis in critical areas of the frame.



			Load case 1 (see fig. 2)			Load case 3 (see fig. 2)			Load case 5 (see fig. 2)		
Ref. nr.	*Strain gage nr.*	*Element nr.*	*Meas.*	*Calc.*	*Differ. (%)*	*Meas.*	*Calc.*	*Differ. (%)*	*Meas.*	*Calc.*	*Differ. (%)*
1	2	118937	294	244	17	296	283	4.3	413	341	17.4
2	49	98607	270	241	9.6	154	147	4.5	260	233	10.3
3	3	118872	307	274	10.7	149	177	18.7	268	246	8.2
4	5	98558	191	207	-8.3	204	214	-4.9	282	295	-4.6
5	52	119547	172	169	1.7	-8	-15	-	60	57	5
6	11	97469	146	140	4.1	192	205	-6.7	253	265	-4.7

Figure 6 - Comparative analysis of the results of tests and calculations

10. Conclusion

The publication of the standard EN 13749 codifies in Europe the design process of the bogie frame and identifies clearly responsibilities of the customer and the supplier of the bogie design. For the acceptance procedure of a bogie design the norm defines a path of verification activities that guarantee that a new bogie design is compliant to all quality and resistance requirements.
The acceptance process allows also to produce a complete technical dossier concerning the verification of bogie design.
Finally it is important to underline that some important aspect still remain open points and are not yet defined in the norm. The items which will require research work in the next years are mainly two: the first one is the analysis and calculation methodology to evaluate the multi-axial fatigue in the bogie frames and the second one the need to standardise design loads and parameters for tilting train bogies related to the maximum non compensated acceleration of operations.

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