

# **Methodology for Condition Assessment and Retrofitting of Railway Bridges.**

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## **Abstract**

Railway lines consist of steel truss bridges which are very old and have many problems due to inadequate maintenance system or need to increase its capacity to carry higher loads. To undertake above challenges there should be proper procedure to evaluate these bridges. This paper represents methodology for condition assessment and retrofit existing railway bridges. It start from basic condition assessment and runs up to developing detailed numerical model and at the end suitable methods is proposed to retrofit the bridge to full fill the requirements. All major steps were briefly described and all other important facts are mentioned.

**Keywords:** truss bridge, condition assessment, FEM model, validation

# 1. Introduction

There can be many reasons which can cause to assess existing railway bridges. Some of them are bridge has been subjected to changes such as deterioration, mechanical damage, repair or change of use. Other reasons can be bridge was designed according to the out dated design code and it has to be checked with new codes and various increasing new traffic requirements. The problems occurs when assessing these bridges are mechanical characteristics of material are not known and corrosion of the material has reduced the effective thickness of structural elements.(3)

The most suitable method for assessment will depend on the cause for the need of the assessment and the desired capacity. This paper provides general guide line for asses steel railway bridges and according to the requirement methodology need to be adjusted. One of the main reasons for the increased interest and frequency in published work is lack of funding to replace aging steel bridges with increasing demand on railway traffic assessment procedure.

## 2. Assessment criteria

An assessment criterion is given in flow chart in figure 1. Assessment is described by step wise procedure and each step is described in detail in this paper.

### 2.1.1 Initial condition assessment

The assessment usually begins with the initial condition evaluation which requires examining existing documents visiting the bridge for inspection. Aim of this study is to identify current condition of the bridge. However this assessment is about existing structures, so the knowledge about the actual bridge condition will be essential. A site visit with inspection of the bridge is necessary. This will not cover any detailed evaluation. If condition of the bridge is good without any further evaluations it is possible to move next step which is development of suitable finite element model for further evaluation. Existing documents such as built drawings and sketches from initial site visit will use to develop the model. Initial evaluation decides that bridge requires detail evaluation in initial assessment stage evaluator must be determine which areas needs to be investigated in detail in order to find their cause, extend, consequently their effect on structural behaviour and carrying capacity. For initial condition evaluation required information will be bridge geometry, material properties and construction type etc. Whether to do simple or detail evaluation decision should be made by prior experience of the evaluator.

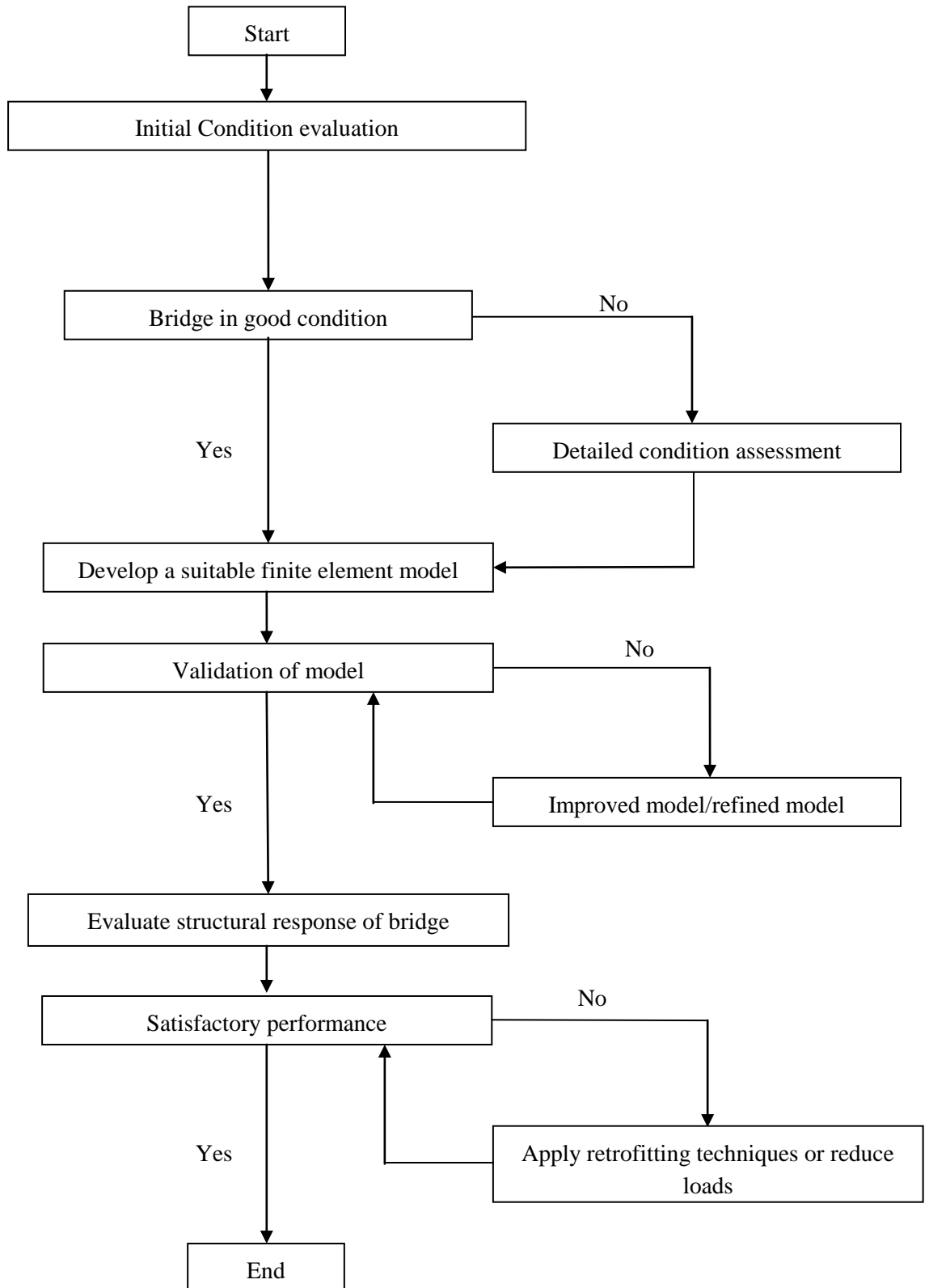


Figure 1. Assesment procedure

### 2.1.2 Detailed condition assessment

From initial assessment if the decision is to do detailed assessment then all the required areas of the bridge needs to be evaluated further. During this process all data collected from condition assessment will be used. (*BRIME, 2001*) This process will include following steps (1)

- Study the existing documents and check their correctness.
- Detailed inspection.
- Supplementary investigation

It is possible to conduct last two stages using different levels of accuracy and complexity

#### **Study the existing documents and check their correctness.**

In this process all the existing drawings and all other supplementary documents will be collected and their correctness will be examined with the actual site condition. In site dimensions of all members must measured and any changes must be recorded.

#### **Detailed inspection**

This is the one of most important process of assessment. Most of the railway bridges are very old any there can be many defects in structural members such as corrosion, deformations and poor connections.

Corrosion is the most difficult type of defect to asses from defects above mentioned. Corrosion is thermodynamically spontaneous chemical reaction that inevitably occurs over time under ordinary environmental conditions. (2) Reasons for corrosion can be in proper maintenance system, design did not pay much attention to the durability requirements and expose to salts when bridge is near to the sea. Assessing corrosion it is required to assess current amount of corrosion as well as rate of severity of corrosion, but forecasting of future rate of corrosion is extremely difficult. The loss of cross-sectional area can be measured either mechanically or with ultra sound equipment. Types corrosion can classify as given in the table1.(2) Elastic modulus and yield strength is not affected by the corrosion . But properties such as sectional area, second moment of area, radius of gyration and section modulus can change. Some of these properties do not change linearly with thickness. As a result at the end failure mode of structure can be changed.

So at this process all the data about type of corrosion and dimensions of the corroded area must be recorded in a suitable manner which can be asses later. Other than that other defects such as deformations and poor connections needs to be recoded

Table 1. Types of corrosion

Type	Description	Cause
Uniform	Relative uniform section loss, occurs over large area	Surface uniformly exposed to corrosive environment
Pitting	Formation of pits (localized penetrations), occurs over small area	Mechanical damage to steel surface creates a starting point for pitting
Galvanic	Localized, typically severe section loss, occurs in areas of dissimilar metals in contact	Dissimilar metals at connections, washers/bolts, welds, etc.
Crevice	Localized, elongated penetrations, occurs in confined areas	Low concentration of dissolved oxygen in deep crevices that collect water
Stress	Rapidly progressing cracking, usually in stainless steel, high strength steel or aluminum	Members in a corrosive environment subjected to tensile forces

### **Supplementary investigation**

In this process other important parameters such as yield stress of material, ultimate stress and young's modulus of material need to be investigated by laboratory as well as field test. Problem of these bridges are since they are very old exact details about material properties are not known. Conducting laboratory tests such as tension tests, chemical analysis/metallographic tests, fatigue tests these properties can be obtain respect to current condition of the bridge.(4) A sufficient number of specimens needs to extracted from the webs of the upper and lower chord of the main girder and from the web of the transverse beams, and the members must be fully restored with riveted plates

- Chemical analysis/metallographic tests - useful for the material identification (To grade the type of steel used in the bridge)
- Tension tests - Mechanical properties determined by tensile tests, with the relevant parameters  $f_y$  -Yield strength/elastic limit.,  $f_u$ - Ultimate tensile strength,  $\epsilon_u$ - Ultimate elongation
- fatigue tests- given e.g. by fatigue resistance curves/S-N-curves, sample should be obtained from structural members which as prone to fatigue.

Other than above mentioned, field measurements such as strain gauge measurements, acceleration measurements and deflection measurements can be obtained by using appropriate loading on the bridge. Loading can be dynamic or static. If the speed of the train is less it is possible to use suitable dynamic factor to represent dynamic effect and perform static load test

to take measurements. Location of strain measurement is depending on importance of each member. Location of deflection gauges and accelerometers will depend on span of the bridge and past experience.

Other than that data about past loading history and expected future loading will be important when evaluating fatigue life to the structure.

### **2.1.3 Develop a suitable finite element model**

Depending on results of above investigation suitable FEM model must be developed. Model can be simple 1D beam model or fully detailed 3D model which depends on requirement. Usually we named these bridges as steel truss bridges there are points to consider whether that is correct. The joints are not point-like and the connections between adjacent elements make use of a large number of nails and additional plates, this suggests that bending moment may be transmitted by the joint (3). Recent research work suggest that best option for model is 3D frame model. One of important parameter when validating model is fixity of connections. If fully fix condition does not give close results to the field measurements rigidity of connection can be changed by using springs at the joints. Then stiffness of the spring can change to validate the model. Space frame elements can be used to model superstructure and to model gusset plates one dimensional rigid bar element can be used. Model can be liner or non linear but for reduce complexity initially liner model is proposed. (elastic material properties)

One of great challenge in modelling is taking corrosion in to account. The high variability of corrosion development makes it difficult to establish clear, consistent procedures for assessing damage. Models have been proposed to predict the expected corrosion penetration of steel bridge girders (Kayser and Nowak 1989; Cheung and Li 2001), the accuracy of these models depends on highly variable, often unavailable environmental data. A well-formulated prediction model simply does not exist. Thus a condition assessment typically requires a quantitative analysis based on partially subjective data. This was addressed by various ways in literature. One simple method proposed by K. Lima .etal 2008.

Corroded members usually have a highly unpredictable geometry. For members in tension and compression establishing appropriate values of cross-sectional area is an essential part of the design evaluation process. The remaining net area, as measured for the corroded section (see figure 2), should be reduced to achieve a value that is statistically determined to be representative of the minimum net area of the corroded cross section. Depending on the nature of available corrosion data, arrival at an appropriate value may require a certain measure of engineering judgment. This approach to analysis demonstrates the importance of accurate and representative section measurements during the condition assessment. After evaluation it is possible to categorize corrosion damage in pre identified categories starting from small corrosion to severe damage. Then in the model it is possible to reduce percentage of area for all that particular type of damage.

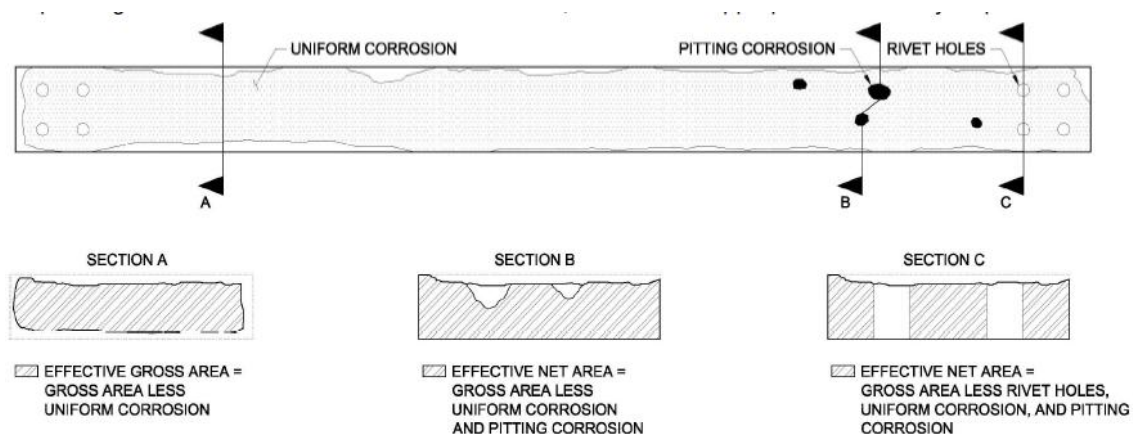


Figure 2: Effective net areas due to corrosion

### 2.1.4 Validation of model

Process involved in this step is to compare the results of the FEM model with the outcome of the load test to identify the most reliable model and to estimate reliability. Loads for bridge in validation of FEM model should be actual loads used in load test and need to place or move according to pre-planned method. If simple model cannot provide satisfactory results some parameters of the model need to be change to achieve reliable results or model need to be refined or advance analysis options such as non linear material behaviour can be included. Either static or dynamic tests can be use to validate the model. Natural vibration modes, frequencies and measurement of displacements, accelerations will provide global response of the bridge. Natural vibration modes and natural frequencies can be obtained by after leaving the train from the bridge. But tests should be performed to both sides of travelling of train. Displacement of bridge can measure at few point both vertical and horizontal inducing at the middle. Local tests such as strain gauge measurements used for additional information (reliability of using local measurements to calibrate is not clear (3)). To obtain accurate acceleration data they must be pre-process before identification. Pre-processing includes removal of mean, existing trends, noise contaminations etc. Fast fourier transformation method can be used to obtain acceleration spectrum to use in analysis.

### 2.1.5 Evaluate structural response of bridge

After validating the model that can be use to check the adequacy of the bridge for new loading conditions such as increase of speed of train or increasing the weight of the train or any other requirements such as earthquake loading. This process must ensure structural reliability of the model in strength, stability, serviceability and fatigue. Since defects of the bridge is included in the model may be stresses in the individual structural elements can be differ from initial design. So capacity check must be carried out for at least for critical members. Kayser and Nowak (1989) outline a method for determining the capacity of deteriorated steel girders. The proposed method applies structural analysis techniques to a model providing information about the expected locations and rates of corrosion. The governing internal stresses in steel bridge girders

are considered for bending, shear, and bearing, as is the behavior of connections in corroded members.. However, tensile and compressive resistances typically govern the design of truss members, and so are relevant to the assessment of many bridges. The following approach is suggested, without developing it further: “capacity is computed as the net remaining area times the tensile strength.” For connections, it is similarly suggested that the capacity is directly related to the corrosion-reduced net area.(3). Other than that bridge superstructure must be checked for satisfying global requirements such as deflection in most cases for serviceability loads it must be less than  $1/200 \times \text{span}$  and modes of vibration (first mode should be linear).

### **2.1.6 Apply retrofitting techniques or reduce loads**

If above analysis gives unsatisfactory performance then, retrofitting techniques need to be applied. Some methods are providing additional plates where damages are severe, replace full member and removing of surface coat of paint and apply new surface coat such as anti-corrosion paint and coal tar to stop future corrosion.

## **3. Conclusion**

The study presented here is a research effort that aims to investigate a general procedure to estimate assess load carrying capacity of railway bridges. Field investigations need to be done up to required complexity depending on the requirement and condition of the bridge. After field investigations numerical model is proposed to develop and bridge models have been refined based on the outcomes of field tests. Then validated model can be used to find out performance of the bridge for different types of loading or to obtain any other performance of the bridge.

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