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Recommendations for rehabilitation and corrosion protection of a 100-year-old steel bridge (Durgadee) across heavily polluted river near Mumbai, India

S. S. Bhonge[1], P. Dalwi[2],
J. K. Kulkarni[3], S. K. Manjrekar[4]
*Contact author: bhongess@gmail.com
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ABSTRACT
This paper describes the rehabilitation proposal, methodology of evaluation of distress and likely remedial measures for 100 years old steel bridge on Ulhas river, near Mumbai. The bridge is constructed in year 1914 during British era apparently now heritage bridge as it was constructed with unique structural arrangement of jack arch decking and warren truss girder with verticals. After structural audit in 2000, it revealed the deterioration of steel parts and concrete initiated long back because of humid atmosphere and pollution in the area. Durgadee bridge showed various signs of bridge distress like major cracks in masonry abutments, heavy corrosion of Mild Steel (MS) structural members, non -functioning of expansion joints and bearings, failure of jack arch roof plates, de-bonding of concrete and exposed reinforcement etc. Paper discusses recommendations for rehabilitation and corrosion protection.
Keywords: corrosion protection; rehabilitation; distress; steel structure; LCNR.

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[1] The Superintending Engineer, Designs Circle (BR), P.W.D., Govt of Maharashtra, India.
[2] Executive Engineer, PW Division Thane, India.
[3] Retired Executive Engineer, MIDC, Govt of Maharashtra, Mumbai, India.
[4] Director, Sunanada Speciality coatings, Mumbai, Hon. Member ACI India, India.

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Recomendaciones para la rehabilitación y protección contra la corrosión de un puente de acero de 100 años de antigüedad (Durgadee) sobre un río muy contaminado cerca de Mumbai, India

RESUMEN

Este documento describe la propuesta de rehabilitación, la metodología de evaluación de la angustia y las posibles medidas correctivas para el puente de acero de 100 años de antigüedad en el río Ulhas, cerca de Mumbai. El puente se construyó en el año 1914 durante la era británica, aparentemente ahora puente de patrimonio, ya que se construyó con una disposición estructural única de cubierta de arco de gato y vigas de celosía con verticales. Después de una auditoría estructural en 2000, reveló el deterioro de las piezas de acero y el hormigón iniciado hace mucho tiempo debido a la atmósfera húmeda y la contaminación en el área. El puente Durgadee mostró varios signos de angustia en el puente, como grietas importantes en los pilares de mampostería, corrosión intensa de los miembros estructurales de acero dulce (MS), no funcionaban las juntas de expansión y los cojinetes, falla de las placas de techo de arco de gato, desacoplamiento de concreto y refuerzo expuesto. El documento discute recomendaciones para rehabilitación y protección contra la corrosión.

Palabras Clave: protección contra la corrosión; rehabilitación; angustia; estructura de acero; LCNR.

Recomendações para reabilitação e proteção contra a corrosão de uma ponte metálica de 100 anos de idade (Durgadee) sobre um rio fortemente poluído perto de Mumbai, Índia

RESUMO

Este artigo descreve a proposta de reabilitação, metodologia de avaliação de perda de capacidade resistente e prováveis medidas corretivas para uma ponte metálica de 100 anos de idade no rio Ulhas, perto de Mumbai. A ponte foi construída no ano de 1914, durante a era britânica, agora como ponte histórica, uma vez que foi construída com arranjo estrutural exclusivo de decks em arco e viga vertical treliçada. Após uma inspeção estrutural em 2000, foi revelada a deterioração dos elementos de aço e concreto iniciadas há muito tempo por causa da atmosfera úmida e da poluição na área. A ponte Durgadee mostrou vários sinais de deterioração da sua estrutura, como grandes fissuras nos pilares de alvenaria, corrosão avançada dos elementos metálicos estruturais, não funcionamento das juntas de dilatação e aparelhos de apoio, falha das chapas metálicas do deck em arco, desplacamento do concreto e armadura exposta. O documento discute recomendações para reabilitação e proteção contra corrosão.

Palavras chave: proteção contra corrosão; reabilitação; perda de capacidade resistente; estrutura de aço; LCNR.

ABBREVIATIONS AND ACRONYMS:

Heritage Bridge Structure: Structure recognized by State Govt for its historical and aesthetical significance.
PWD: Public Works Department of State Govt in charge of infrastructure construction and maintenance.
MPCB: Maharastra State pollution Control Board who monitors pollution.
LCNR: Long Chain Nylon Reticulant protective coating.
IRC: Indian Road Congress, an organization in India controlling road and bridge design standards.

1. INTRODUCTION

This paper describes the need for rehabilitation proposal, methodology of evaluation of distress and likely remedial measures for 100 years old steel bridge (also known as Durgadee bridge) on Ulhas River at km 1/ 800 on Bhiwandi road, Kalyan, near Mumbai.
The bridge is constructed in year 1914 during British era apparently now heritage bridge as it was constructed by British engineers with unique structural arrangement of jack arch decking and warren truss girder with verticals. The bridge is a steel structure with two columns filled with concrete with Steel superstructure consisting of jack arch type deck support sheet.
Steel structures in severe atmosphere must face a variety of environmental forces. Although several deteriorating processes, chemical attack still represent severe challenges and problems to many important steel structures. Rapid development in technology in recent years has made easier to control such deteriorating processes.
Structural steel offers several advantages:
High strength: the yield stress of steel in tension and compression is almost the same which helps us in the use of steel as long span bridges and tall structures.
Durability: this property of steel allows successive deformation without significant loss of strength and stiffness including resistance to weathering action.
Prefabrication: steel parts are manufactured at factory under strict supervision and quality control due to which there is a very less variation in material properties. The material can be transported at site and assembled which helps in speedy construction ensuring better quality.
Demountability: steel structure can be disassembled and reused if required. It can be recycled easily reducing the wastage. Even the repairs and retrofitting of steel structure and their strengthening is much simpler and easier than the concrete structure.
Limitations: steel structure are susceptible to corrosion when exposed to air and water.
Although structural Steel are not combustible, they lose their strength rapidly during fire. Aesthetically, steel structure does not give pleasing appearance. The cost of steel structure is more than that of concrete
The choice of section in steel structure is governed by:

- Cross section area, to resist tension or compression.
- Section modulus to resist bending and shearing stress.
- The radius of gyration to provide rigidity towards buckling in compression

2. GENERAL- INDIAN SCENARIO

India is home to various geographical features such as rivers, mountains, valleys, tablelands, long seashores, deserts, and flat terrains. India is the seventh largest country in the world and covers a total area of 3,287,263 sq km. The shoreline of the country extends for 7,517 km.
India has one of the largest road networks in the world with about 59 lakh km of road length including National Highways (NHs), Expressways, State Highways, District roads, Other District Road and Village roads. In India, road infrastructure is used to transport over 60% of total goods and 85% of total passenger traffic. India has inventoried more than 4 lakh bridges/structures constructed through various Government bodies.
The bridges in coastal areas were constructed in the face of several adverse factors, such as difficulty of fixing water way, navigational requirements, approach alignments, foundation problems, saline conditions, difficulty of construction of superstructure and approach banks, Navigational requirements. These in turn, sometimes required bridges having long spans involving sophisticated construction procedures. Foundations were usually deep in the creek bridges and standing water posed major problem in construction.

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Due to extraordinary increase in traffic densities, particularly in and around main cities of the state, the Government has undertaken a program of constructing flyovers, underpasses and bye-pass roads. But before a decision of new construction, priority to rehab and retro fitting of existing bridge is given. As the Durgadee bridge has outperformed and proved its durability because of its robust structural arrangement. Bridge after rehabilitation, can act as bypass for LMV (light and medium vehicles) and city users in the city of Kalyan.

3. PRESENT SCENARIO OF DURGADEE BRIDGE

Kalyan is near Mumbai and is historical place and was famous Trade Centre due to Kalyan creek coast. There exists one fort known as Durgadee fort along the side of the bridge which is around 400 years old. Similarly, Bhiwandi is a Taluka place and equally important historical Trade Centre. In early parts of 19th century the British Government decided to connect Kalyan and Bhiwandi by steel bridge across Ullas river near Durgadee fort. The construction of bridge started somewhere in 1908 and was commissioned in 1914. (Bridge site location: 19°14'43" N 73° 6'59" E)

- **Abutments:** These are rubble masonry abutments on both sides, however abutment on Bhiwandi side seems to be in very dangerous condition and need the replacement.
- **Bridge consist of 10 spans of 36m each having total length of 360m with through truss arrangement Superstructure and Decking arrangement**: There is a continuous flooring system of Jack arch over the stringer beam for all 10 numbers of spans. Signs of upheaval of BT layer shows that there is immediate need of replacement. The expansion joints of the bridge are completely damaged and blocked.
- **Wearing course:** There is an immediate need of dismantling bituminous wearing course removing cleaning the debris on bridge bearing and over the jack arch decking sheet. The condition of deck steel plates in Jack arch due to corrosion would be visible only after removal of wearing course and the layers below it. The distress mapping of superstructure is needed by exposing the one or two spans after dismantling wearing course.
- **Bearings:** The type of bearing is steel rocker and roller type and not visible due to lots of debris deposited on the bearing location. Arrangement of Rocker / roller type bearings is nonfunctional because of lack of maintenance.
- **Substructure:** It consist of twin hollow steel column filled with concrete and tied with cross bracings.
- **Bridge foundation:** Consist of pile foundation with steel liners. MS liner in splash zone, i.e. portion between high and low water levels, shows extreme corrosion.
- **Present corrosion protection arrangements:** No protection is given to exposed surfaces from Corrosion /carbonation and other atmospheric pollution.

In addition, above, general causes of distress in structure, following have played major role in damaging the structure and reduction in service life.

After structural audit in 2000, it revealed the deterioration of steel parts and concrete initiated long back because of humid atmosphere in the Kalyan area, carbonation of concrete, chloride ingress, leaching, sulphate attack, which all lead to the corrosion and ultimately reduction in life of structure. Bridge is closed for traffic since 2001. Figure 1 shows Google map of bridge.

Any bridge structure in service life will be subjected to chemical and physical changes. A durable structure is one in which these changes occur at a slower rate which does not detrimentally affect its performance within its intended lifespan. As per Indian codes and other contemporary codes, the steel structures are designed for a maintenance-free operating life of 60 to 100 years. However, the various structures in and around Mumbai area show severe deterioration (or failure in many cases) within a very short span due to aggressive environment and humidity in atmosphere. In

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present case generally aggressive environment added by polluted water of Ulhas river is playing major role for deterioration.
Based on the studies, the water from river cannot be considered safe even for irrigation purpose. The chloride content in the wastewater effluent was with an average value of 1,377 mg/L. The results indicate that the chloride content is very much above the acceptable limit of 200 mg/L set by WHO. The results indicated high level of pollution due to toxic heavy metals like chromium (Cr), cadmium (Cd), nickel 6 (Ni), zinc (Zn), copper (Cu), lead (Pb) and iron (Fe). The concentration of all these heavy metals were found to be much above the acute toxicity level.
Because of heavy pollution in Ulhas river, water and the humidity due to nearness to seashore, the bridge condition is very dilapidated. There is heavy corrosion of steel parts used in the structure. The structure must have been designed for normal river water in 1914. It is however seen that the color of river water is blackish which may be due to mixing of wastewater of surrounding urban areas and industrial waste. River water contains both organic and inorganic chemicals in addition to various gases like H2S, CO2, CH4, and NH3 etc., that are formed due to the decomposition of sewage. This leads to faster deterioration of steel structure and concrete.

Figure 1. Google map of bridge.

4. DISTRESSES NOTICED IN DURGADEE BRIDGE

Durgadee bridge showed various signs of distress as under:

- Minor to major cracks in Masonry abutments on both sides. Abutment on Bhiwandi side is in dangerous condition on the verge of giving way.
- Non -functioning of expansion joints and bearings.
- Heavy Corrosion of MS structural members. However, loss of section up-to 3mm due to corrosion was noticed at less than 10 % of the area.
- Leakages through Jack Arch deck and near bearings.
- Failure and deterioration of Jack Arch roof plates for decking of bridge as well as concrete filling above it is including wearing course.
- De-bonding of concrete and exposed reinforcement in concrete below wearing course.

State Transport Department (called as PWD) has already stopped the vehicular traffic on the bridge since 2001.

5. DRAFT POLICY/ PROPOSED STAGES OF REHABILITATION AND REPAIR

The whole program of restoration of this bridge can be divided into the following parts.

1. Study of old records related to bridge

- Verify the original design work done by PWD, Material specifications used during the construction period.
- Study of Restoration, repair done by PWD from time to time in past.
- Detailed mapping, dimensions and preparation of detailed drawings for Old Bridge structure with help of Drone and physical survey. It will include use of drone survey for preparation of Auto cad drawings and dimensioned drawing which will be needed for structural modelling and analysis.

2. Inspection

Steel bridge will be inspected with the purpose of identifying any defects that may be present in the structure and to establish causes for these defects. Defects that are likely to affect the strength, safety or serviceability of a bridge are planned to attend as part of the remedial and maintenance work cycle.

- Photographs (both recent and historic); The most recent inspection reports; Recent maintenance history.
- Strength and rating calculations. Condition survey of bridge will lead to estimation of residual life of the structure.
- A visual inspection will systematically cover the whole surface of the steel structure at close quarters paying particular attention to areas.
- The following matters are critical to the success of a steel bridge inspection:
- Detailed notes must be taken of the condition of the protective coating on all parts of the structure using a standard method of assessment
- Signs of rust staining should be looked for around the heads of fasteners. This may indicate that they are loose.
- Fasteners which do not conform with proper standards of installation should be noted.
- The highest loaded bolt or rivet in a joint should be carefully examined in areas which are expected to be susceptible to fatigue.
- The presence of a suspected crack should be confirmed by non-destructive testing, Dye penetrant and magnetic particle techniques are likely to be used in the first instance. Radiographic and ultrasonic methods may also be used for specific cases.
- Deformations and distortions will often show up as cracking or flaking paint. Measurements of any significant deviations from the true line should be recorded.
- The location and description of all defects must be methodically recorded to allow proper evaluation of their effects and subsequent monitoring or repair.

3. Study of corrosion parameters related to various bridge components that is corrosion mapping.

4. Various types of NDT (Non-Destructive Testing) to assess the damage

5. Testing of river water.

6. Planning for working platform for working of labor and machinery

Suspended or hanging platform will be needed for working below the soffit. Detailed drawings will be prepared for above cases considering site situation and methodology of repair. Ideally floating pontoon with small boat along with winch machine will be very useful for speedy execution of work. Figure 2 is a photo of bridge showing bearing and expansion joint location.

7. Underwater assessment of the part of the substructure and foundation

Special types of cameras and certified divers will be needed as water due to turbid due to pollution. It will involve underwater videography and taking photographs and Submission survey details in soft copies and status report of underwater survey. Total number of piers to be survey will be 9 piers of bridge.

Figure 2. Photo of bridge showing bearing and expansion joint location

8. Evaluation of defects

All observed defects will influence the strength or serviceability of the bridge. Defects which reduce the capacity or durability of the bridge do require remedial action. The purpose of evaluation is to determine the relative significance of each defect so that the load-carrying capacity of the bridge can be reassessed and so that any remedial work required can be given proper priority. Evaluation will also assist in determining future strategies for maintenance or replacement.

The evaluation of the effect of some defects requiring a thorough understanding of the behaviour of the structure concerned. The interaction of primary and secondary load-carrying members, the effect of imperfectly pinned joints and the possible presence of alternative load paths need to be appreciated. A basic understanding of metal fatigue and crack mechanics is necessary to evaluate problems of this nature.

9. Analysis of factors to decide methodology of rehabilitation/ strengthening

Structural repair and maintenance of steelwork includes the replacement and maintenance of protective coatings, repair of corroded members, replacement of damaged members and defective fastenings, and remedial work associated with fatigue cracking. These problems have been identified during the inspection and evaluation process.

Fatigue behavior is very much influenced by the presence of stress concentrations such as holes, welds, abrupt changes of shape, cracks or other defects.

10. Residual life Assessment and bridge rating

a) Residual life Assessment and bridge rating as per design analysis before and after rehab.
b) Assessments to enhance the residual life by further by about 15 to 20 years.
c) Assessing the existing load rating which may vary from 30 R to 60 R to decide the suitability of bridge for vehicle traffic.

11. Action plan for Corrosion Protection

The detailed evaluation of corroded material is to be carried out by laboratory testing in ICT (Institute of Chemical Technology), Matunga Mumbai, India and Metallurgical testing of steel at Metallurgical Department, IIT (Indian Institute of Technology) Powai Mumbai, India.
Plan on the various technology and material available for repair and its methodology with reference to economic consideration. Corrosion protection system to protect the bridge for further 25 years including sacrificial anode system to prevent the further corrosion and its damaging action.

12. Selection of appropriate repair, restoration and rehabilitation measures to various structures.

6. METHODOLOGY PROPOSED: SALIENT FEATURES AND PARAMETERS TO BE CONSIDERED

6.1 Steel girder repair

Figure 3 is a photo of the bridge showing the warren truss type structure. The work of repairing built-up steel girders by restoring or replacing damaged or deteriorated elements include, but is not limited to, providing temporary supports for jacking; modifying girders to accept jacking loads; temporarily supporting or reducing loads carried by girders; disconnecting or removing elements from girders by removing bolts or rivets; drilling and reaming holes; grinding to provide required finish or tolerances on steel surfaces; making minor repairs to decks within the work area; erecting repaired or replaced elements and incidental items by welding or high tensile strength bolting; and preparing surfaces damaged or left bare by the work and applying a prime coat of paint.

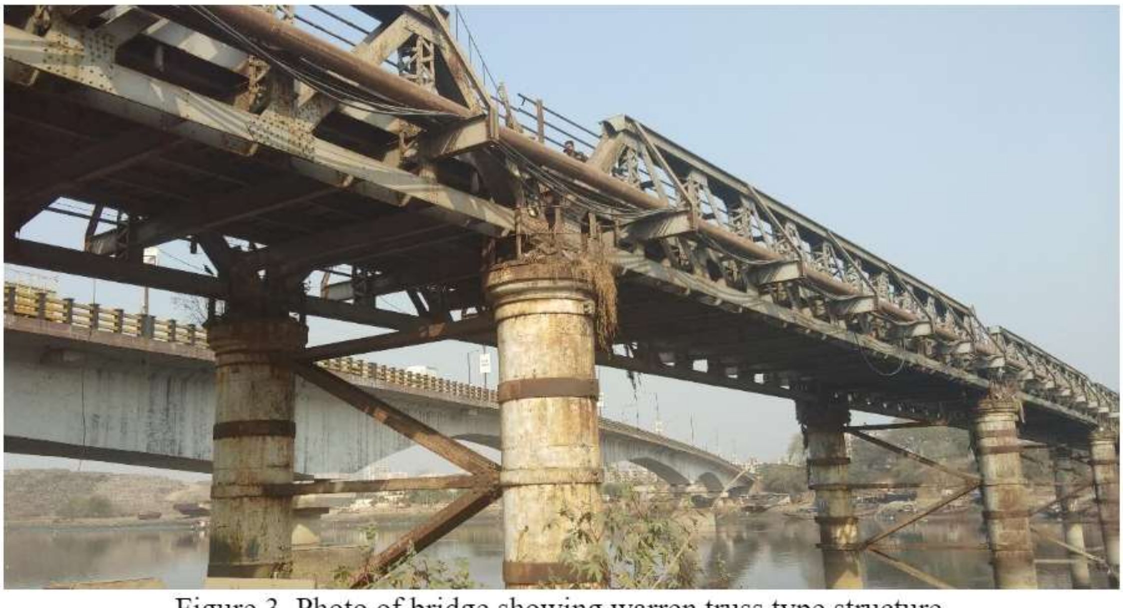

Figure 3. Photo of bridge showing warren truss type structure.

6.2 Protective coating failure

It is rare for a protective coating to outlast the life of the structure. Breakdown of paint or loss of any coating is inevitable and should be anticipated. This usually results from condensation and may be increased by absorption of moisture by wind-borne salts on areas not subject to rain washing. Accumulation of debris, bird droppings, flaking paint etc. will all retain moisture and promote corrosion.

In addition to eventual failure of a coating system by weathering, premature failure may result from:

- Loss of coating adhesion due to faulty specification or application;
- Incompatibility of successive coats;
- Subsurface rusting due to inadequate surface preparation and/or priming paint;
- Localized failure due to mechanical damage;
- Inadequate film-build on sharp edges, welds and paint shadow areas.

6.3 Loss of section

Where the protective coating has not been maintained or an area of damaged coating not been repaired, corrosion resulting in a loss of section usually follows. The corrosion rate largely depends on the proximity of the bridge to the coast.

Corrosion can also be accelerated by the following situations:

- Presence of cracks and crevices.
- Different metals in contact.
- Ponding of moisture.
- Concentration of salts through evaporation; rust and debris.
- Loss of section may also result from wear in pins or from mechanical abrasion where members rub together.

6.4 Loose or defective fastenings

Whether operating in shear or in a friction grip joint, fastenings must be properly installed to function correctly. Sometimes, because of excessive vibration, over-straining, corrosion or improper installation, fastenings can become loose and should be replaced.

Specific problems typically associated with various types of fastenings are:

- Mild steel bolts tend to corrode rapidly if the protective coating is not intact. This type of bolt may also loosen with vibration unless suitable washers or lock nuts are provided;
- High-strength bolts will also corrode unless the protective coating is maintained. Galvanized bolts are usually better than painted 'black' steel. Improperly torqued bolts will loosen and bolts which have been installed through heavily tapered flanges without suitably tapered washers may flex and become overstressed.

6.5 Cracks

Cracking of any bridge component is potentially serious and needs to be thoroughly investigated. Cracks in steel bridge members can be caused by metal fatigue, embrittlement, impact damage or manufacturing defects such as rolling flaws, and can extend with time. Structural cracks are most likely to have started at obvious stress concentrations such as a bolt or rivet hole, extremities of welds, abrupt changes of section, or at nicks and notches.

Fatigue cracks might not become obvious until a member has been subject to many stress reversals or fluctuations.

6.6 Impact damage

Accidental damage to bridge members through vehicle impact is a serious matter and one which needs to be investigated promptly. Obvious damage will usually be in the form of bent and distorted members and overstrained fastenings.

6.7 Deformation and distortion

A structural member's resistance to compressive forces is considerably reduced if components are buckled or distorted out of plane. Tensile members can act unpredictably. Deformation and distortion can occur as a result of:

- Accidental damage.
- Axial over-strain.
- Excessive shear in thin webs.
- Seized bearings.
- Inadequate provisions for expansion.
- Substructure settlement may also lead to distortion in members.

Deformations cause members designed for tension being forced to take compressive loads.

6.8 Manufacturing defects

Despite the rigorous specifications and the tight manufacturing tolerances to which structural components are rolled and formed, manufacturing and fabrication defects can and do find their way into completed structures.

Rolling flaws may show up as delamination, cracks, blisters, pits or inclusions as well as out-of-tolerance straightness or lack of squareness.

6.9 Faults in detailing

Regrettably, defects can be built into a bridge structure through poor design, detailing and specification. In this category are found such details as:

- The abrupt curtailment of steel section flanges in tension members.
- Excessive eccentricities (both in plane and out of plane) in joint intersections.
- Inadequate provision for rotation.
- Poor drainage provisions.
- Curtailment of welds in inappropriate locations.

Manufacturing defects as well as design flaws can sometimes be noticed through a drone tour as illustrated in figure 4.

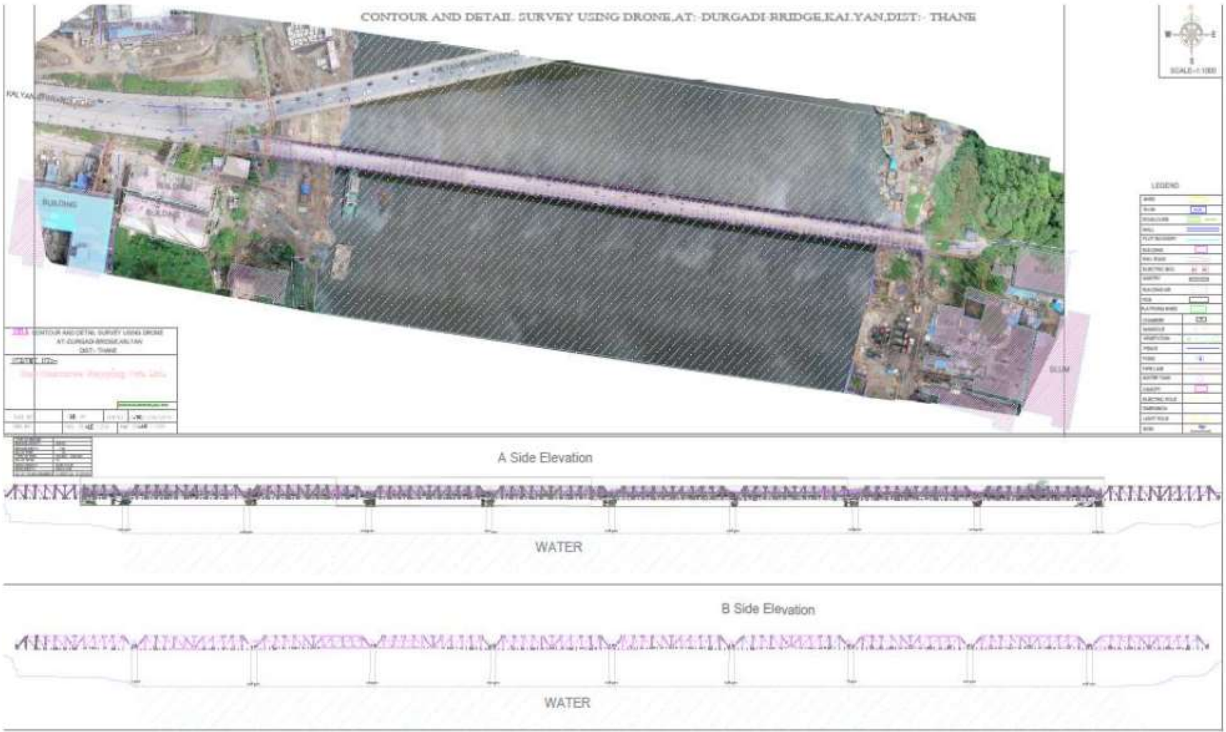

Figure 4. Drone survey map of bridge

7. PROPOSED METHODOLOGY AND PROCEDURE FOR CORROSION PROTECTION

7.1. The Composite Treatment of LCNR (Long Chain Nylon Reticulant) UV (Ultraviolet) Resistant Coating along with Electrochemical Protection by sacrificial anodes

It will be necessary to evolve 'State of the Art' corrosion removal, highly adhesive, UV resistant coating system and include electro-chemical protection to further prolong the life of protective system. This paper attempts to choose such composite system based on test parameters and past track records of innovative systems.

The points to be considered for rendering new protective systems:

- The surface should be totally bereft of any residual paint as well as even the traces of corrosion product as life of corrosion protection systems are dependent solely on surface preparation.
- The corrosion free surface should remain so (after corrosion removal treatment) until the next logical treatment of appropriate polymer primer is received by the surface.
- Primer should be followed by especially cross linked and highly impenetrable matrix of polymers.
- These coatings should have full immunity from the decomposition due to attack of ultraviolet radiation in the sunlight.
- Corrosion is an electro-chemical process and in highly susceptible conditions like Durgadee bridge, it is possible for it to get promptly initiated whenever smallest amount of exposure to bare metal either due to defects inadvertently left during the execution due to extremely high intricate arrangement of steel members or during the initial service life due to unintentional injuries to protective systems happens and then the entire corrosion could be vigorous. Thus, it is preferable to give electro-chemical protection like use of sacrificial anodes at regular intervals typically at the junctions.

7.2. Procedure of rectifications

- Since the removal of entire residual remains of the paint as well as adamant corrosion products to the extent of absolute 100% is a challenging situation by steel wire brushing etc., the only option is to sand blast the whole steel structure.

As a result of sand blasting, the corrosion products and residual paint are removed fully, however it also leads to creating a very vulnerable steel surface which is susceptible for 'flash corrosion' due to moisture and oxygen in the ambient conditions. This layer of flash rust can be visible within even 2 to 3 hours of sand blasting in the form of reddish iron oxide layer. This layer then onward creates compromise to some extent in the loss of adhesion of subsequent polymer/epoxy/polyurethane coatings.

- In order to avoid this weakness in the protection system, as soon as sand blasting is over, one layer of Rusticide is applied.

Rusticide can be applied by cotton waste, soft brush etc. Rusticide not only removes the residual rust but also reacts with corrosion products to convert them to a stable passivating nano film on the surface of the steel and return the steel back to its original grayish white color the steel from flash rusting. As a result of application of Rusticide, the steel surface turns into whitish-black colour.

- Now this surface is totally free of corrosion product and ready to receive the priming coat of 100% pure LCNR - epoxy primer - Sunepoxy 358. Epoxy coat is always a primer coat for two reasons:
  a. It has extraordinary adhesion to steel or any other dry surface.
  b. The outstanding adhesion of epoxy ensures the successful performance of subsequent protective coats.

Epoxy coatings are not to be given as finishing layers as it easily gets disintegrated by ultraviolet rays or any form of external energy.
Sunepoxy 358 is a specially made epoxy primer which has longer chain nylon reticulant molecule which enhances its performance as compared to ordinarily available general epoxy coatings.

- Corrosion Protection with Acyclic Polyisocyanate Reticulant (APR) based Sungard APR Epoxy coatings are not UV stable and hence it needs additional protection of UV stability.

After 24 hours of application of Sunepoxy 358, provide and apply 2 coats of Sungard APR using soft paint brush / spray gun, etc. Polyurethane coatings are resistant to attack of ultraviolet rays. However, in case of Sungard APR the normal polyurethane molecule has been added with the characteristics of acyclic polyisocyanate reticulantness, making the matrix more complex due to additional cross linking and hence added denseness of the cured polymer. This adds to the robustness and protection to a higher degree.
There will be need of Rollers with long handles (metal sticks), spike shoes on horizontal surfaces.

- As mentioned earlier corrosion is an Electro chemical process and LCNR coating system will give protection to the surface covered by the same. However, Durgadee bridge structure is having several intricate steel members welded together. Also, at several places the steel flats or channels are arranged on each other which means that the coating cannot be physically done in such an area either by spray or brush. Hence, the surfaces so unattended are vulnerable to corrosion. The corrosion thus initiated will be very rigorous as seen in some of the photographs. At such situations, it is very useful to operate sacrificial anode. This sacrificial anode is connected to the vulnerable areas by welding and wherever corrosion attack takes place sacrificial anode being more vulnerable will corrode preferentially leaving the steel surface unaffected.

The placement of sacrificial anodes shall be more focused at gusset plate weld joints and at major junctions etc. Where the possibility of proper protective coating will be difficult.

- Deck slab will be re-concreted by using welded studs for anchoring purpose. Required slope of 2.5% for camber and to facilitate drainage will be provided. Stripe seal type expansion joint and new steel rocker roller bearing will be provided.

8. PREVENTIVE MAINTENANCE

8.1 The preventive maintenance of a steel bridge starts after completion of rehabilitation as proposed above.

Provision of access to facilitate future inspections and maintenance should also be considered. Other practices which will assist in minimizing maintenance of an in-service bridge include:

- Proper selection of protective coating type, proper surface preparation and application over the entire coated surface and its periodicity of application.
- Regular washing and cleaning of protective coating surfaces.
- Regular clearing and cleaning of drainage ports. Improving drainage in areas which are not adequately drained.
- Ensuring bearings are operating correctly.
- Maintaining the presence of adequate expansion joints.
- In addition, potential problem areas should be identified, and appropriate action taken before structural defects become manifest. Such matters include:
    - i. Details involving abruptly curtailed cover plates on flanges should be improved if they are likely to become fatigue risks;
    - ii. Poor welds should be ground out and replaced;
    - iii. Selected rivets can be replaced with high- strength friction-grip, fasteners to improve the fatigue characteristics of a rivet group (e.g. the leading rivets in a joint or cover plate);
    - iv. Eccentricities in joints and connections may be improved to reduced unwanted bending stresses;
    - v. The point of support of bearings may be redefined to improve eccentric movement effects.

8.2 Bridge instrumentation systems for dynamic monitoring of bridge.

Baseline model development of a bridge is essential for structural health monitoring which can play an important role in securing system integrity, minimizing maintenance cost, and maintaining longevity of bridges. Structural health monitoring and baseline model are required periodically, especially after damaging earth quacks, degradation of a structure due to aging or environmental actions or if there is a damage-causing event such as impact due to accident or natural disaster.

Global structural health monitoring technology consists of two aspects: (1) Instrumentation of bridges with sensors such as accelerometers and strain gauges and more importantly, (2) Methodologies for obtaining meaningful information concerning the structural health conditions, if any, from the measured data.

Advances in sensing, digitizing, recording, and data communications have led to current monitoring systems capable of sensing, recording, and remotely analyzing/displaying dynamic input and response information for bridges and other structures.

The current generation of sensors for earthquake accelerometers has large dynamic ranges, allowing simultaneous measurement of earthquake shaking, low-frequency wind-induced vibration, and ambient vibration.

Proposed baseline model development of this bridge, which will be instrumented for global structural health monitoring. Monitoring systems including accelerometers, strain gauges, pressure sensors, and displacement sensors to be installed.

A structural health monitoring system may detect unusual structural behavior at an early stage, thereby reducing the risk of sudden and catastrophic failure. Appropriate monitoring requires the development of an accurate computer model that effectively characterizes the entire structure, including the continuity and boundary conditions.

9. CONCLUSION

The steel bridge though has outlived its service life; however, it is still in serviceable condition with Engineered Strengthening and Corrosion protection. It also enjoys status of Heritage structure. Appropriate strengthening of steel and concrete deterioration is brought out. Its service life enhancement can be done with Life 365 Model of ACI since the damage and rectification is focused around with enhanced properties coatings and the attack of chloride and other aggressive pollutants. Major emphasis in corrosion control will be creating long term barriers for protection against heavy pollutants to come in contact of steel. Protective treatment is also suggested considering coastal conditions of Mumbai and around. The protection program is drawn on the basis of successful past track record of similar structure in similar conditions. The restoration will serve purposes like retaining heritage structure at the same time it will be useful for at least LMV for few more years reducing traffic load on the existing bridge.

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11. BIBLIOGRAPHY AND STANDARDS

Malhotra, M. M. (2007), *Design od steel structure*. Edition: 7, Reprint Publisher: Jain Brothers.

Indian Road Congress (IRC) (1990), *IRC: SP:35-1990: Guidelines for Inspection and Maintenance of Bridges*. (Reprint-2000), Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (1996), IRC: SP:18-1996: *Manual for Highway Bridge Maintenance Inspection*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (1999), IRC: SP:52-1999: *Bridge Inspector's Reference Manual*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (2007), IRC: SP:74-2007: *Guidelines for Repair and Rehabilitation of Steel Bridges*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (2008), IRC: SP:75-2008: *Guidelines for Retrofitting of steel Bridges by Pre-stressing*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (2002), IRC: SP:60-2002: *An Approach Document for Assessment of Remaining Life of Concrete Bridges*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (2004), IRC SP 61-2004: *An Approach Document on Whole Life Costing for Bridges in India*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (1993), IRC: SP:40-1993: *Guidelines on Techniques for strengthening and Rehabilitation of Bridges*. Indian Road Congress Special Publication. New Delhi.

Indian Road Congress (IRC) (2010), IRC: SP:37-2010: *Guidelines Evaluation of Load Carrying Capacity of Bridges*. Indian Road Congress Special Publication. New Delhi.

MPCP (2019), *Maharashtra State Pollution Control Board* (MPCP), URL: http://www.mpcb.gov.in/node

Maharashtra Pollution Control Board (2015), *Comprehensive Study on Polluted River Stretch of Ulhas River – Downstream of Mohane, Kalyan,* MPCB Kalyan.
Karve, S. R. Shah, V. I. (1998), *Structural Design Databook Steel Structures*, Structures Publications.
NZ Transport Agency (2001), *Bridge Inspection and Maintenance Manual*. URL: https://www.nzta.govt.nz/resources/bridge-inspection-maintenance-manual/