GENERAL:

The structure is reinforced concrete railway bridge of arch form which is built about fifty year ago. Its free span length is 40 meters and its width is 4.6 meters. It was recently strengthened by the use of Carbon Fiber Composites. Strengthening was done without closing down the bridge from traffic.

The project commenced in May 1999 and finished in August 1999.

STRUCTURAL CHARACTERISTICS:

This bridge facilitates transporting of crude oil from the harbor to the local oil refinery. Under current conditions, weight of a fully loaded freight train is approximately about 15 tons per axle.

The bridge consists of reinforced concrete arches on both sides. The two arches are connected in between with reinforced concrete crossbeams with the railroad track laid down in concrete-encased hanger columns. The railway track lies on top of wooden ties on a bed of crushed rocks supported by the concrete slab and beams spanning 40 meters between supports.

During the investigation reinforcing corrosion, concrete spalling and numerous cracks were found in the arches, hanger columns, beams and slabs. These conditions were determined to have been caused by the excessive loading that the bridge had to carry. The moisture in the air and concrete carbonation had also contributed to the weakening of the structure.

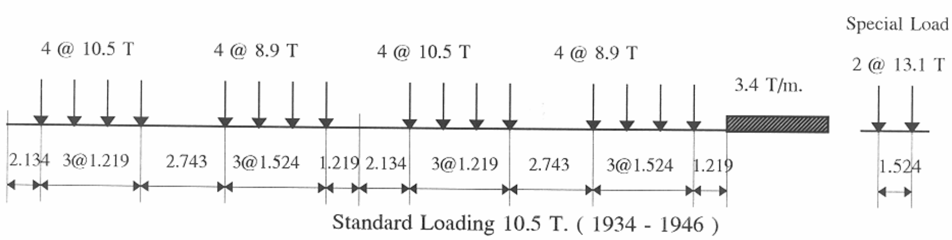
This bridge is a State Railway Arch Bridge and was registered in the "Arch Bridge Preservation Register" with the Department of Fine Arts. This register mandated that any repair work had to conform to Architectural Preservation standards. The State Railway elected to strengthen the bridge with the use of carbon fiber composites.

REASONS FOR THE REPAIR:

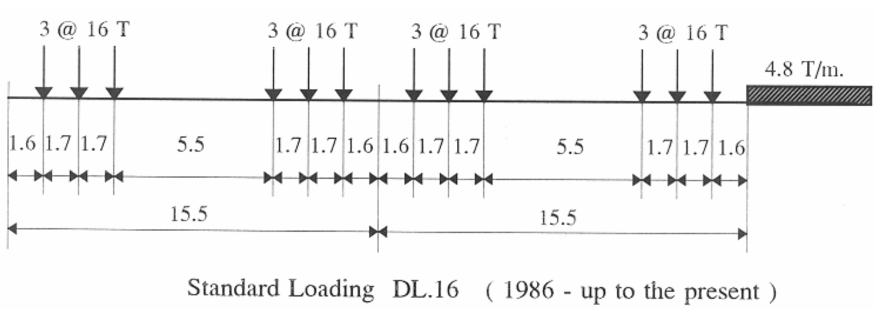
1. Reinforcing steel corrosion and the numerous cracks that were found on the arches, beams, hanger columns and underneath the slab.

2. The State Railway wished to increase the bridge's load carrying capacity.

Standard loading used for design



New standard loading used for redesign



INSPECTION/EVALUATION METHODS:

1. When visual inspection was carried out, damage from corrosion and concrete deterioration was found. It was estimated that 15% of the superstructure was damaged. Cracks were clearly visible in 25 different areas.

2. After opening up the concrete surface for inspection, it was estimated that approximately 5 to 25 % of total structural strength of reinforcing steel had already been lost due to corrosion.

3. Four groups of samples were collected for concrete compressive strength tests. A figure of 150 Kg/cm^2 was determined as a result. An ultrasonic pulse technique was used for checking and the bridge was found to be in fairly good condition and amenable to strengthening.

4. Test results determined the concrete pH value of about 12.

5. To use carbon fiber for strengthening of the flexural and shear strength of the superstructure, a pull-off test had to be done to determine the viability of using that technique. This pull-off test was used in more than 30 areas. Average failure stress in the substrate layer was found to be 25 Kg/cm^2. This was determined to be sufficient enough.

6. Before strengthening, a LVDT instrument had been installed to check for slab deflection. After strengthening, by using the same locomotive, the deflection was reduced by about 26 to 30%.

7. Strain gauges were attached at the outer surface of the composites. Strain was measured while the locomotive was passing by. The obtained results were determined to be satisfactory.

Description of Historic Arch Railway Bridge Rehabilitation Project

CAUSES OF DETERIORATION:

Overloading of the bridge beyond its capacity, various environmental factors and the long period of service were determined to be the causes of deterioration.

REPAIR SYSTEM SELECTION:

Using finite element method for investigation of superstructure under the new Standard loading, it was found that the reinforcing steel would not be able to resist the induced tensile stress. Carbon fiber composites had been selected for strengthen the superstructure due to its lightweight, ability to resist all types of environmental corrosion and ability to maintain the architectural and structural characteristics of the existing structure.

For this project, Carbon fiber sheets were used for increasing flexural strength and shear strength at major areas of the structure, and glass fiber sheets were used to wrap around the superstructure to prevent corrosion.

STRENGTHENING OF THE SUPERSTRUCTURE:

1. The Arches were strengthened to increase flexural and shear strength.
2. Crossbeams were strengthened to increase flexural strength.
3. Hanger columns were strengthened to increase confinement and axial force capacity.
4. Slabs were strengthened to increase flexural strength.

SITE PREPARATION:

The bridge was situated in the landscape that limited visual distance and thus safety precautions were very important during the repair work. The width of the bridge was only 4 meters wide and we only had 1 meter on both sides to set up. The scaffolding and equipment had to be set up without interfering with the freight trains which ran by over the bridge every 30 to 90 minutes and also without interfering with the barges running under the bridge at all times of the day.

Scaffolding was set up on both sides of the bridge. A movable platform was installed underneath the bridge under difficult circumstances with limited space between the bottom of bridge and the top of the barges that passed by.

Radio communications were used between conductor of the freight train and the construction crew, and a fire truck stood nearby the site at all times because of the volatile nature of the crude oil the freight train was carrying.

Surface preparation processes were determined to be able to yield satisfactory results.

CONCRETE REPAIR WORK:

1. Old Concrete was saw cut and the deteriorated concrete was removed.

2. A pneumatic needle was used to inject a sealer to remove corrosion from the affected steel.

3. The entire structure was sandblasted.

4. A cementitious anti–corrosion coating was applied with a bonding agent and then patched with repair mortar.

5. Cracks were repaired with a low viscosity epoxy injection. Major crack areas were stitched with carbon fiber composites.

COMPOSITES STRENGTHENING:

1. Before installation of carbon fiber sheet, surface preparation was done. Surface preparation of concrete consisted of all required concrete repair procedures, and then the sandblasting of the entire surface.

2. An epoxy primer was applied to improve the bond strength to the system.




3. Epoxy putty was applied for leveling and smoothing the surface.

4. Fiber sheets were installed with an epoxy adhesive to strengthen the superstructure.

5. After strengthening with composites, a latex coating mixed with cementitious materials was applied over the carbon fiber to add UV protection. The repair work was completed with an application of a finish with a colored texture.

6. Pull-off test was done again and it was found that fiber sheet could bond very well with concrete surface. No bond failure was found.

UNFORESEEN CONDITIONS FOUND:


Description of Historic Arch Railway Bridge Rehabilitation Project

1. Heavy rainfall continued for many weeks while the project was on its way. This made surface preparation and other works more difficult. All surfaces must wait until dry up before installation of fiber sheet.

2. Crushed rocks on top of slab had to be removed before repairing of slab. All rocks must be filled back as soon as possible after the work finished. Track had to be reset and leveled. All processes consumed a lot of time and were difficult because of freight trains, which will run by over the bridge every 30 to 90 minutes.

3. Oil stain spreaded through out many areas. This caused surface preparation work to be more difficult. When crushed rocks were removed out, more corrosion was found.