Bridge Bearing Replacement Using Flat Jacks

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Abstract: Replacement of bearings is typically done by jacking to raise all beams at a headstock sufficiently to free the bearings for replacement or resetting. To avoid damage to the structure and to restore the initial bearing reactions, it is necessary to exercise tight control over jacking displacements and the final levels of the new bearings. The process may be complicated by the presence of epoxy of variable thickness above or below the bearings. Traffic delay due to the road closure is a significant impact and may be extreme if problems extend the night works into the morning peak.

An alternative approach is to replace bearings individually using flat jacks as well as hydraulic jacks. The method is to support the bridge on hydraulic jacks adjacent to the bearing to be replaced, with a very small (sub-millimetre) upward displacement. As the bearing is removed by demolishing the pedestal or mortar pad under it, its load is transferred to the locked-off hydraulic jacks. A new bearing is installed on a permanent flat jack which is inflated with epoxy to restore the previous load on the bearing and hydraulic jacks, which are removed once the epoxy has gained strength. Displacements and loads are monitored throughout the process. Only brief road closures are required.

The method was used successfully to replace bearings at two bridges on Ipswich Motorway in Brisbane.

The method may be appropriate for situations involving major roads, a structure sensitive to relative displacements, bearings with variable epoxy depths, very wide bridges, or where only isolated bearings require replacement.

Keywords: bridge, bearing, replacement, flat jack

1. Background

The Safelink Alliance upgraded the Ipswich Motorway between Wacol and Darra, with practical completion in 2010. The Alliance comprised the Queensland Department of Transport and Main Roads (TMR), CPB Contractors, BMD, AECOM, and Arup. The motorway is a major route for commuter and freight traffic.

The scope of work included the construction of bridges M101 and M102, as shown in Figure 1, which carry Ipswich Motorway over Bullockhead Creek. Bridge M101 carries the northbound carriageway and Bridge M102, which varies in width, carries the southbound carriageway and an on-ramp. The bridges have two spans of teforff girders supported on laminated elastomeric bearings.

These bridges experienced unexpected settlement and lateral movement after the girders had been placed, resulting in the shear displacement or slip of some bearings. The outcome of investigations into the problem was a decision to replace or reset 16 of the total 52 bearings.

Freyssinet was subsequently engaged as the specialist subcontractor for bearing replacement.

2. Objectives

The objectives of the rectification works were to:
- Replace or re-set the bearings to comply with the full SM1600 design loading.
- Return the girders to pre-existing levels to reinstate deadload reactions on the bearings.
- Not damage the permanent works (particularly diaphragms and deck joints).
- Minimise disruption to traffic during night works, with no disruption during busy times.
3. Relevant Structural Details

The diaphragms had been designed for jacking loads, however they are short stiff members and sensitive to differential displacements during jacking. The capacity is limited by the close spacing of the girders reducing the lap length of diaphragm reinforcing bars between adjacent girders. The cross fall of the deck also led to the bars not being in contact at the splice. There is no direct shear connection between the diaphragm and the deck slab. There is some composite action through shear connection at the ends of the girders. It was therefore necessary to limit relative displacements between jacking points to avoid damage to the diaphragms.

The girders were detailed with a tapered steel plate attached to the soffit to provide a horizontal bearing surface despite the longitudinal grade of the girder and its end rotation at the time of erection. In general the taper of the plate is not perfect and a thin layer of epoxy is permitted to fill any gap between the plate and the bearing. The presence or not of epoxy at any particular bearing could not be discerned by visual inspection.

The bearings were seated on a reinforced concrete pedestal without a mortar pad. Inspection showed the presence of epoxy at the base of some bearings. The extent of the epoxy under the bearings was unknown.

Each abutment headstock has two lateral restraint blocks with dowels into the diaphragm to resist transverse loads. There is no restraint to longitudinal movement at the abutments. The restraint blocks do not leave space for jacks between the adjacent girders.
4. Initial Structural Analysis

The bridge decks were modelled by grillages to assess the loads applied to each bearing. The behaviour of the diaphragm during jacking was analysed for many scenarios in a continuous beam model. When uncracked section properties were used, small differential displacements created large bending moments and shear forces in the diaphragm, leading to the finding that the diaphragm would experience flexural cracking. This was not seen as a serious problem. Reinforced concrete is designed to crack, and the duration of the loading would be brief. Cracked section properties were then adopted, and the lower, cracked stiffness also reduced the diaphragm loads.

The diaphragm capacities were determined taking into account reduced lap lengths and partial lack of composite action with the deck slab. A limit of 0.5 mm was specified for differential displacement between adjacent jacks.

Traffic restrictions were also required to keep heavy trucks away from the edges of the bridge to avoid overloading the end jacks and cantilevering diaphragm. Traffic lanes could remain open with reduced speed and shoulders closed to traffic on the bridge.

5. Selection of Jacking Method

Three alternative methods were investigated for replacing or re-setting the nominated bearings taking into consideration the effects on the permanent structure components during and after the bearing replacement process, potential disruption to traffic during bearing replacement, and risks associated with the bearing replacement operation.

Conventional Jacking

The conventional approach is to jack up the full superstructure at each abutment in turn, replacing the nominated bearings, and re-seating other bearings with their shear displacements released. This operation would be undertaken with jacks between every girder (except where there are shear keys), with a hydraulic system which enables the uniform stroke displacement of the jacks to a tolerance of 0.2 mm or better, so that the bridge could be raised off the bearings without significant loads in the diaphragms from differential displacements. The initial expectation was that this method would be adopted.

However, more detailed consideration revealed some risks associated with the conventional approach in this situation:

- The replacement of only some bearings is not conventional. It is normal to replace all. Program constraints did not favour the procurement and replacement of all bearings.
- The presence or potential presence of epoxy on both top and bottom surfaces of the bearings makes it difficult to achieve tight level control when the bridge is lowered. For the bearings to be replaced, the epoxy, which would be of variable and unmeasurable thickness, would be removed and could not be replicated exactly.
- The new bearings would not precisely match the height of the existing bearings. The manufacturing tolerance on overall height for the relevant bearings is +/-4 mm. The new 157 mm nominal height bearings, already procured, ranged in height from 154.5 mm to 155.2 mm.
- The bearings to be re-set rather than replaced would be re-seated in a different position on the pedestal after the shear displacement is relieved. Any epoxy under these bearings would probably need to be removed and thus change the level of the bearing.
- In some cases, the new bearings would be positioned outside the footprint or too close to the edge of the supporting pedestal due to the unexpected movement of the abutment. As a result, those pedestals had to be rebuilt or extended prior to the jacking operation in this case. This would introduce risks associated with potential undermining or damaging the bearings during partial demolition of the pedestal.
- The new bearings would have a somewhat different stiffness than the existing bearings.
These difficulties could be mostly overcome by removing any epoxy on both top and bottom of all the bearings, spreading a fresh thin layer of epoxy on top of all the bearings and lowering the bridge on the jacks so that the beams were supported in contact with the epoxy but without loading the bearings until the epoxy gained strength. This is how individual girders are placed during construction. The issue here is that every girder at an abutment, up to 18 in number, must be done simultaneously. This was considered a risky operation, with major traffic disruption if it could not be completed overnight.

**Resetting of Existing Bearings**

Some of the concerns about the mix of new and existing bearings in the conventional method could be alleviated by not replacing any bearings, but resetting them all instead. This method is otherwise similar to conventional jacking, with the risks of still not maintaining levels on reseating or of untimely completion of night works.

**Flat-jack Method**

The flat jack method was suggested by Freyssinet who have long experience in the use of flat jacks in various applications, including bridge bearing replacement. A flat jack (originally patented by Eugene Freyssinet in 1938) comprises two thin steel sheets connected via a circumferential ring to create a single internal space into which fluid can be pumped under pressure, deforming the steel sheets. It has compact height and is able to lift heavy loads over small distances.

Using this method, only one bearing is replaced at a time, thus:

- The diaphragm is supported with hydraulic jacks adjacent to each nominated bearing in turn. The diaphragm is raised only slightly, a fraction of a millimetre, and the jacks locked-off.
- The existing bearing is removed by demolishing the plinth under it. Load is progressively transferred to the adjacent hydraulic jacks.
- A new, lower plinth is constructed with space for a flat jack below the new bearing.
- Load is transferred to the new bearing by inflating the flat jack under the bearing with fluid epoxy until the load is transferred from the adjacent hydraulic jacks to the new bearing, which is compressed during this operation.

The advantages of this method are the small bridge displacements at all times, the irrelevance of epoxy layers on the existing bearing, the insensitivity to the precise thickness and stiffness of the new bearing, and the close restoration of load into the new bearing. As the adjacent elastomeric bearings still carry their share of dead load and contribute in carrying traffic loads the stresses in the diaphragm in this method are considerably lower compared to the conventional jacking method. Above all, the jacking operations are brief and require limited night time lane closures. In addition, any modification or extension of the bearing pedestals, where required, could be carried without affecting the bridge traffic and with no significant risks to the permanent structure. On the other hand, the overall program is longer.

In view of the particular circumstances and risks at these bridges, the decision was taken to proceed with the flat jack method. It presented the most reliable solution at this site, and it addressed the major concerns. The limitation of 0.5 mm differential displacements between adjacent jacks derived for the conventional jacking method was applied for the differential between adjacent girders for the flat jack method.
6. Detailed Analysis and Specification

The method described in principle in Section 5 required considerable development in design, specification, and work methods. The jack positions for the edge, shear key, and typical bearings are shown in Figure 2. A mechanical compression load cell was specified to be placed directly above the hydraulic jack so that the load on the locked-off jack could be monitored. Displacements transducers were placed at the jacks, on the beam where the bearing was being replaced, and on the adjacent beams.

![Figure 2 Jack Positions](image)

In the initial stage of jacking, the hydraulic jacks were pumped to produce a reaction of about 10% of the calculated bearing reaction in order to firmly seat the elements of the jack assembly, including the load cell, jacking stool, and several bearing plates. The initial load was achieved with a very small upward deflection of the diaphragm. The jacks were then locked-off. The precise load and displacement at this stage were not critical. The purpose of this stage was to insert new, stiff supports with known initial loads and levels.

As the plinth was demolished under the bearing, the load on the locked-off jack and all the displacements were monitored. The increase in the load on the load cells was a measure of the load that was on the bearing.

When the flat jack is inflated the load is transferred back from the load cells to the new bearing. This process continues until the load cells are at their initial load and level, indicating that the new bearing load matches the original bearing at the initial stage.

Finally, the hydraulic jacks are released and the new bearing should have the same load and be in the same position as the original bearing.

All these stages were analysed for the three types of bearing positions, and jacking forces, displacements, and diaphragm loads were predicted. The end bearings have the heaviest deadload and total reactions, and the jacking force is increased by the cantilever effect. A single 400 t jack was needed for the end bearing and pairs of 260 t jacks elsewhere. Provision was also made for a 150 t auxiliary jack directly under the end girder. The roadway shoulders adjacent to the end bearings were closed for the duration of the works to avoid the possibility of heavy truck loading immediately adjacent to the barrier.

The theoretical relationships between loads and displacements are dependent on assumptions of stiffness for all the structural elements, including existing and new bearings, the jack assembly including load cells, and the diaphragm. Obviously, these stiffnesses cannot be known precisely. Considering the large forces and very small deflections, it was recognised that some adjustments might be needed in practice.

The method replaces one bearing at a time, but to progress the works efficiently it was desirable to be working on two bearings simultaneously, though not on the same step of the process. As jacking for one bearing has some effect on nearby bearings, a sequence was established whereby at Abutment B1 where
all bearings were to be replaced, two bearings could be replaced simultaneously provided there were five other bearings in between.

An epoxy mortar was specified for the new plinth in order to achieve strength sooner. On completion, the flat jacks were encased in epoxy for durability.

7. Installation

The procedure was developed jointly by the design and installation teams, and was detailed on the drawings with 4 phases and 30 steps. Freyssinet produced a work method statement to provide detailed site procedures including safety requirements.

At an early stage, Freyssinet, conducted an informal trial in a laboratory test loading facility to demonstrate the behaviour of the proposed rectangular flat-jack with a 10 mm thick bearing plate against the specified elastomeric bearing. The flat jack successfully compressed the bearing to a load in excess of the maximum required jacking load.

Following preparatory works, the bearing replacements commenced with an external bearing (as shown in Figures 3 and 4) and a bearing adjacent to a lateral restraint block. These bearings were representative of the most difficult situations in the replacement program. They were treated as test cases to compare the assumptions made during the analysis phase with the site measurements and to assess the effectiveness of the planned work methods. The main findings were that the jack assembly was not as stiff as assumed and required additional jacking to maintain acceptable displacements during the bearing load transfer. It was necessary to employ the auxiliary jack for the end bearing.

Figure 3 Set-up at End Bearing
A hydraulic jack assembly including the stool, bearing plates, and load cell was then tested at the TMR laboratory and gave a non-linear stiffness with an average value of 740 kN/mm for the load range between 200 kN initial load and 600 kN maximum load during installation. The graph shown in Figure 5 illustrates load-displacement recorded in one of the tests carried out on the jack assembly.

![Graph showing load-displacement relationship](image)

**Figure 5**  Jack assembly stiffness test- Load/Displacement diagram
The structural models were re-run with a similar stiffness. The procedures were amended to require higher initial jack loads with upward deflections of the diaphragm of 0.2 mm typically and 0.3 mm for an end bearing. The use of the auxiliary jack was mandated for end bearings.

The remainder of the bearings were replaced without further changes to the method. However, some matters of practical detail did emerge. It is difficult to lock off hydraulic jacks in the initial stage to the intended precision. There was often a loss of load and displacement, and the step had to be repeated until the planned outcome was achieved. The new bearings undergo some very early creep displacement and it was sometimes judged on site to slightly increase the flat jack pressure to compensate for this. Representatives of the Designer and the Independent Verifier were always on site to make and agree such judgements.

The diaphragms had been inspected for cracks before works commenced and were again inspected on completion. Careful observation did not detect any cracks at either inspection. This was a very good outcome, but it does highlight the limitations of structural modelling where concrete is normally assumed to have no tensile strength.

8. Discussion of Girder Displacements

As previously mentioned, a number of displacement transducers were installed at positions specified on the drawings for each of the bearings to record the displacements of the jacks and girders throughout the bearing replacement process. The data was analysed to check the progressive and final displacements of each girder and the differential displacements between adjacent girders recorded throughout the various stages of the process. When adjacent bearings were replaced, the data include the displacements induced during the replacement of both those bearings. The summary data for maximum differential between adjacent girders and at completion of the operation, and the relative displacements of the girder form its original position are presented in Table 1.

<table>
<thead>
<tr>
<th>Bearing No.</th>
<th>Max differential between adjacent girders mm</th>
<th>Final differential between adjacent girders mm</th>
<th>Final displacement relative to initial level mm</th>
</tr>
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<tbody>
<tr>
<td>A01</td>
<td>0.10</td>
<td>0.10</td>
<td>-0.34</td>
</tr>
<tr>
<td>A02</td>
<td>0.10</td>
<td>0.10</td>
<td>-0.24</td>
</tr>
<tr>
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<td>0.36</td>
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<td>0.18</td>
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<td>0.51</td>
<td>0.27</td>
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<tr>
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</tr>
<tr>
<td>B16</td>
<td>0.04</td>
<td>0.03</td>
<td>-0.16</td>
</tr>
</tbody>
</table>
Points of interest:

- The only final differential between adjacent girders which is greater than 0.5 mm is 0.51 mm between B8 and B9.
- The only final level which is not within 0.5 mm of the original level is 0.61 mm at A18.

B9 and A18 are end girders. A lesson to take from this is that different allowable differential displacements should be specified for end girders because of the different structural behaviour. They have greater bearing reactions, leading to bigger displacements of the jacking system, and the diaphragm is more flexible as a cantilever than as an internal span. The cantilever bending moment in the diaphragm is not proportional to the cantilever deflection. This behaviour would also be found with the conventional jacking method, where 0.5 mm tolerance on the jacks would not necessarily keep end girder displacement within that limit. In general, larger end girder displacements should be acceptable.

**Effect on Traffic**

Jacking operations were carried out during brief (10 minute) full closures of the carriageway. There is tolerance in the initial setting of the hydraulic jacks and typical night traffic has very little effect on loads on the locked-off jacking system (as measured by the load cells). Therefore, undertaking this initial setting operation in future with one or more lanes still in operation could be considered in order to further reduce traffic disruption.

**Conclusion**

The bearings were replaced with close tolerance on level and without any damage to the diaphragms and with only brief interruptions to night traffic.

The method may be appropriate for situations involving major roads, a structure sensitive to relative displacements, bearings with variable epoxy depths, very wide bridges, or where only isolated bearings require replacement.

**Acknowledgements**

The authors thank the Safelink Alliance for permission to publish this paper. The views and opinions expressed in the paper are those of the authors and do not necessarily reflect those of the Safelink Alliance member organizations or of Freyssinet.