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BEHAVIOUR AND DESIGN OF ROCKER BEARINGS IN BRIDGE STRUCTURES

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1. Introduction

Bearings in a bridge transmit the various forces applied from the superstructure to the piers. They are of two basic types: fixed bearings and expansion bearings. Both types need to accommodate the rotations. Fixed bearings permit no horizontal translation. Expansion bearings allow rotation as well as horizontal movement of the superstructure.

The most commonly used types of bearings in bridges are: sliding plate bearings, rocker and roller bearings, elastomeric bearings (elastomeric pads and pot bearings).

Sliding steel plane or curved bearings are used for spans less than 15–18 meters. Rocker bearings are made of cast steel or reinforced concrete and are used frequently in bridge construction, where the bearings are designed to transfer relatively large horizontal movements. There are different types of plain elastomeric bearings used to transfer relatively large vertical and horizontal loads including also movements due to changes in temperature or improper positioning of bridge deck.

Various failures of bearings were observed often causing malfunction or deterioration of structures [1, 2, 3]. The deficiencies of bearings and hinges are not important on the condition of the bearing itself but of some other damages in the structure. They are located where movement has to take place so that if they do not function the eccentric loading appears and the structure may suffer excessive stress. If the movements are restricted, the restraint forces which are not considered in the design, could cause cracking and spalling of the concrete in the girders or substructure cap in the vicinity of bearings.

Movements that bearings must accommodate include:

- temperature change;
- shrinkage and creep of concrete in deck beams;
- deflections of deck beams;
- substructure movements or foundation settlements;
- horizontal bracing and acceleration forces of heavy truck traffic;
- wind actions.

The facts are not sufficiently understood and reflected in the design of bearings. In this situation, the analysis of behaviour of bearings in service seem to be indispensable.

This paper presents the results of theoretical and field investigations of deficient rocker bearings often observed in existing bridges.

2. Defects of bearings and their causes

Classification of bearings defects is presented in table. Two main causes of faulty functioning of bearings can be mentioned:

- faulty positioning or alignment of bearings during construction;
- insufficient maintenance.

To keep the bearings in a good state, periodic maintenance is required. Unfortunately, often no preventive maintenance for long periods of time is envisaged leading to restriction of normal functioning of bearings. In some cases we found the bearings not accessible for visual inspection and maintenance. In these cases the disfunctions of bearings can be detected only by observing the signs of distress in the adjacent structures.

Rainwater with de-icing chemicals, including sand and dirt, penetrates from the roadway through the leaking deck joints to the bridge seat and bearings. The accumulation of dirt and debris restricts the movements

Table 1. Types of defects of bridge bearings

Types of bearing	Types of defect and damage	Most common causes
Sliding plate	• corrosion of plates and sliding surfaces (chemical deterioration) • restricted movement (frozen bearings) • excessive horizontal translation • tearing of plates from concrete seat or superstructure	*leakage of the deck joints; lack of maintenance (accumulation of dirt and debris, no lubrication and painting);* *inadequate design;* *restricted movement on the sliding surfaces (corrosion, debris, dirt)*
Rocker and roller	• corrosion of bearing components • excessive tilting • cracking or crumpling of contact surfaces (pins, rollers)	*leakage of the deck joints; lack of maintenance;* *inadequate design or positioning of bearings (construction misalignment); the effect of creep and shrinkage not considered;* *inadequate design*
Elastomeric	• loss of elastomeric properties (increased rubber hardness) • internal rupture of elastomer, failure of bond between the elastomer and the reinforcement • slippage	*ageing of natural or synthetic rubber;* *environment actions (ozone, chemicals, heat and cold);* *large rotation with high compression;* *excessive horizontal forces*

of the bearings (frozen bearings) and retains moisture for long periods of time. Aggressive water removes the lubricants and corrosion protection coatings from bearing components. A common problem in steel bearings is moisture with chemicals causing rusting.

Corrosion of steel components, including the contact surfaces, which cannot be protected by paint, induces additional locking effect. Preventing translation will cause excess movement at another bearing, preventing rotations can induce large moments.

The faulty positioning of bearings due to lack of proper provision at the time of bearing installation can cause special problems. Figure 1, a shows the cracking and crushing of concrete due to eccentric loading on bearing with sliding steel plates. The excessively tilted rocker bearings were observed in some prestressed continuous beam bridges (Fig 1, b). The excessive translation of sliding plate or segmental rollers can lead to overstress of masonry plate and concrete under the

a) b)

Fig 1. Deterioration of bridge girder corbel due to faulty positioning and rusting of steel sliding bearing (a) and excessive tilting of rocker bearing (b)

loaded plate or to collapse (rejection from the masonry plate) of the roller bearing.

3. Design considerations

The roller bearings must be designed for vertical and horizontal loads. Allowance should be given for rotation and horizontal movement. At present, design of translation of expansion bearings is based on assumption that there is only temperature movements of the superstructure. The effects of creep and shrinkage of prestressed concrete superstructures as well as the deflections of long span girders can cause misalignment.

The causes of such movements can be summarised as follows:

- temperature variation

$$\Delta_T = \alpha_T \times \Delta T^0 \times L, \quad (1)$$

- shrinkage and creep due to longitudinal prestressing

$$\Delta_P(t) \approx \varphi_t \times \frac{P}{AE_c} \times L, \quad (2)$$

- deflection of the girder and rotation of the sections

$$\Delta_\Theta(t) = \varphi_t \times \Theta \times y, \quad (3)$$

- faulty positioning of bearings during construction – Δ_{con}.

Thus, the total tilt of roller bearing is therefore:

$$\Delta = \Delta_T + \Delta_P(t) + \Delta_\Theta(t) + \Delta_{con}, \quad (4)$$

where α_T = linear coefficient of thermal expansion, ΔT^0 = uniform temperature increase, L = length of girder, A = area of cross-section, E_c = concrete moduli of elasticity, φ_t = creep coefficient, Θ = angle of rotation, y = distance from neutral axis of cross--section to extreme fibre of girder.

The horizontal translation of segmental roller is twice less than the horizontal translation of the superstructure with reference to the substructure, ie $a = \Delta / 2$ (Fig 2).

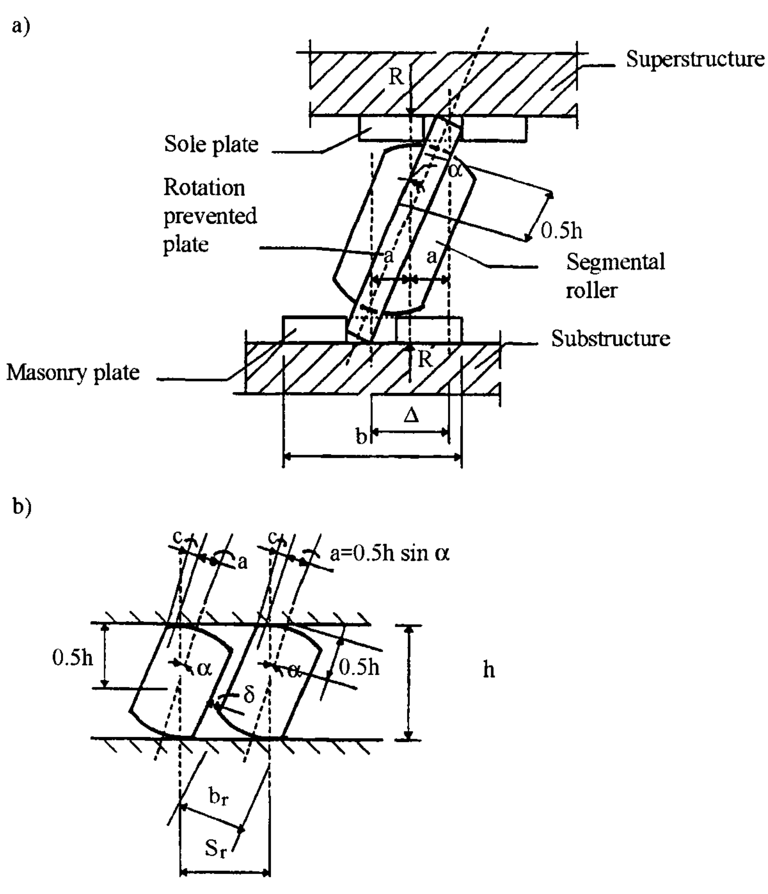

Fig 2. Tilting of single (a) and multiple (b) rocker bearings

Longitudinal movements of bridge decks are much more complex than usually calculated according to Eq (1). The problem results from non-uniform seasonal and daily time-dependent ambient climatic effects. The vertical and transverse temperature distributions in bridge deck are non-linear over the crosssection of a girder leading to plastic hogging or sagging curvatures and rotations and translations of the sections. The combined actions due to prestress, dead loads and thermal loads leading to creep of superstructure may exceed the horizontal displacement levels calculated by Eq (1).

The movements of segmental rollers of expansion bearings should not exceed the values determined from the following conditions (Fig 2):

- permissible contact pressure on the rocker

$$a \le \frac{b_r}{2} - c, \quad (5)$$

where $c \ge 2.5 - 3\,\text{cm}$;

- rotation of movement prevented plate

$$a \le 0.5h(\sin\alpha)_{\lim}, \quad (6)$$

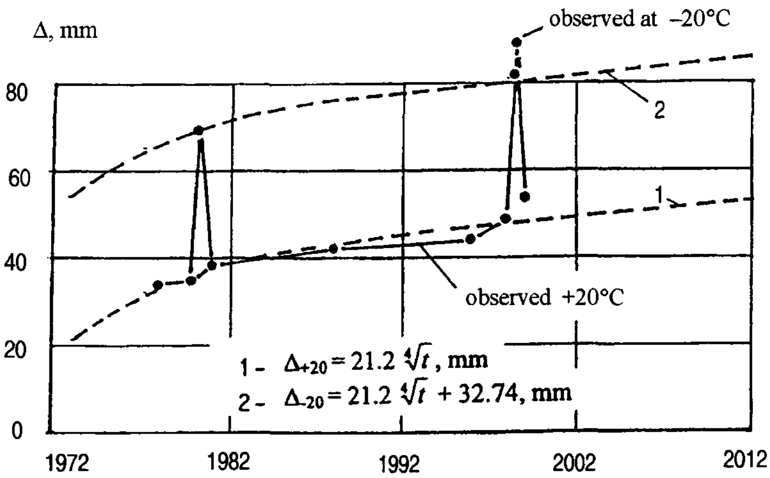

Fig 3. Horizontal translation versus time for the bearing No 4

• position of reaction from superstructure (masonry plate must maintain full contact with the concrete substructure, ie the contact stress at the extremity shall be greater than zero)

$$2a \le \frac{1}{6}b, \tag{7}$$

• clearance between the multiple rollers (no contact with each other at the maximum rotation)

$$a \le 0.5h\left[1-\left(\frac{b_r}{s_r}\right)^2\right]^{1/2}, \tag{8}$$

where s_r is a distance between axis of rollers.

4. Case studies

The bridge investigated is a structure of 341.5 m long and 21 m wide. It is divided into two parts: valley and river. The valley section (an approach viaduct) consists of three simply supported spans each of 36.5 m. The river part is three span continuous post-tensioned concrete box girder of variable cross-section made up of precast segments. The spans measure 62+100+62 m (Fig 4). The bearings of pier No 3 are fixed against longitudinal movement. Expansion bearings are used at other piers and the abutment No 1. Over each pier there are eight roller type bearings.

Excessive tilting was observed during detailed inspections in the bearings at the piers No 2 (Fig 1,b) and No 4. Long term field observations at various times and temperatures of tilted bearings showed that concrete creep under prestress and sustained loads causes continual increase in tilting of bearings (Fig 3). It is important to note that the rockers do not return to their initial position after winter seasons. It seems that observed intensive rusting of the contact surfaces leads to restriction of movements.

Improper movement of the bearings is related to the faulty consideration of temperature provision at the time of bearing installation and lack of adequate provision in the design. Analysis of the bridge project showed that the effects of creep of concrete superstructure was not 2considered in the design for proper positioning of bearings.

Fig 4 shows diagrammatically the deflection of a bridge girder and a horizontal translation of the bearings. The rotation of sections as well as displacements of roller bearings varies with time and depend on the effect of prestressing force and long-term vertical loads. This shortening and deflections results in the following bearing displacement: the edge section of a girder displaced due to deflections by $\Delta_\Theta(t) = \varphi_t(\Theta_3 y_3 + \Theta_4 y_4) = 11.97$ mm and due to prestressing by $\Delta_P(t) = 23.8$ mm when the total displacement as observed in 1999 at +20°C was 49.4 mm. The faulty positioning of bearings during construction is apparent.

The total movement of segmental roller is equal to the algebraic sum of:

- movement due to temperature variations
- movement due to the shortening of a girder resulting from creep

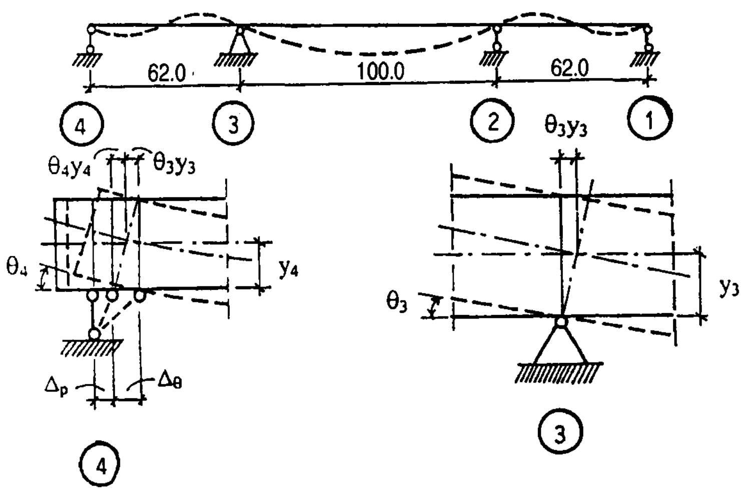

Fig 4. Deflection diagram and rotation of the sections adjacent to supports No 4 and No 3

- movement due to rotation of sections caused by deflections.

Table 2 summarises the measured values of horizontal translation and its limit values calculated by Eq (5), (6), and (7). Apparently, beyond about 9 years horizontal translation of bearings will be approximately equal to its limit value. The jacking of superstructure and realignment to a vertical position of the bearings is inevitable.

5. Conclusions

The principal factors affecting the tilting of expansion roller bearings observed in existing bridges have been discussed and methods for calculating their horizontal translation have been presented.

The factors influencing the expansion bearings behaviour are temperature variation, as well as shrinkage and creep deformations due to longitudinal prestressing and dead load. The determination of long-time movements is complex because these factors produce a constantly changing strain and stress distribution over the depth and span of the bridge decks.

The longitudinal movements of bearings can be evaluated at any time according to Eq 1-4, if the magnitude and the longitudinal distribution of the curvatures associated with material properties, prestressing and loading for the beam span are known.

Case study of three span continuous box girder post-tensioned concrete bridge with excessive tilting bearings is presented. It was found that improper movement of the bearings is related to the faulty consideration of temperature provision at the time of bearing installation as well as the effects of creep of concrete superstructure which was not considered in the design for proper positioning of bearings. The bearings should be realigned to a vertical position after jacking of superstructure.

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Table 2. Horizontal translation of bearings No 4

Horizontal translation a_{eks} in mm measured at +20°C / -20°C	Rate of horizontal translation in mm/year	a_{lim} in mm according to Eq			Prognosis in years when $a_{eks} \cong a_{lim}$
		(5)	6)	(7)	
24.7 / 43.2	0.206	45	45	66.7	8.74 / in 2007

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TILTŲ SEGMENTINIŲ ATRAMINIŲ GUOLIŲ DARBAS IR PROJEKTAVIMAS

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S a n t r a u k a

Analizuojami pagrindiniai veiksniai, kurie turi įtakos tiltų segmentinių paslankiųjų atraminių guolių posvyriams. Pateikiama metodika atraminių guolių horizontaliesiems poslinkiams apskaičiuoti.

Paslankiųjų atraminių guolių darbas priklauso nuo aplinkos temperatūros pokyčių, tilto perdangos susitraukimo ir valkšnumo deformacijų dėl išankstinio armatūros įtempimo bei nuolatinės apkrovos. Ilgalaikius atraminių guolių poslinkius nustatyti sudėtinga, nes dėl minėtų veiksnių nuolatos kinta įtempimų ir deformacijų būvis išilgai ir skersai tilto perdangos.

Atraminių guolių išilginiai poslinkiai pagal pateiktą metodiką gali būti nustatyti bet kuriuo metu, jeigu yra žinomi tilto perdangos kreiviai, kurie priklauso nuo perdangos medžiagų savybių, išankstinio įtempimo jėgos ir apkrovos.

Pateikiamas trijų tarpatramių nekarpyto iš anksto įtempto dėžinio skerspjūvio tilto su neleistinai pasvirusiais atraminiais guoliais pavyzdys. Nustatyta, kad neleistini atraminių guolių posvyriai yra susiję su netinkamu atraminių guolių įrengimu statant tiltą ir valkšnių perdangos deformacijų nevertinimu projektuojant tiltą.

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