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Restoration Design for Capacity Performance Assessment of RC Slab Bridges

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ABSTRACT

Bridges constructed several decades ago have been deteriorated due to many reasons and hence their capacity is reduced. Capacity performance assessment is one of the major tasks to be performed in bridge management and should be exercised with care. Original design documents, drawings and plans are important for such assessment. In the absence of these data, assessing bridge's performance will be a common problem bridge engineer's face. It is mainly due to the absence of any kind of readymade bridge information or a change in design specification. In this case, restoration design should be performed and it is substantial. Experimental results of RC test specimen are used for verification of results and FEM simulations are used for prediction of deflection of the bridge. The result shows the empirical equation is used for the estimation of yield strength of steel and it helps to assess capacity performance of RC slab bridges.

Key words. Restoration design, RC slab bridges, performance capacity assessment, initial conditions, FEM simulation

1. INTRODUCTION

Nowadays constructed bridges are subjected to increasingly heavy traffic loads than expected. This together with deterioration due to external and environmental factors led to decrease in its capacity. Thus, capacity rating of bridges is important. To do this, the initial condition of the bridge should be known.

Restoration design, which is important to estimate the initial condition of bridges, is a basic tool for capacity performance assessment. Non-destructive tests for the estimation of current concrete strength, mid-span deflection of the bridge from load test and position of reinforcing bars using an electric magnetic device are main inputs for the restoration design (Tarekegn et al., 2012).

The deflection of the bridge computed using elastic beam deflection equation, based on the concept of beam theory, may be used to compare with that of the actual deflection measured during load test. Two-and three-dimensional FEM analyses are used for the prediction of deflection of the bridge. From the dimensions of the bridge, deflection and the corresponding load, the areas of reinforcing steel and their actual yield strength will be estimated.

In cases of difficulties to get access to obtain positions of reinforcing bars from the bottom surface of the bridge, load tests at least at two positions should be done. For more accurate results, as many measurements as possible can be taken. The objective of this study is to establish a method to restore the initial conditions of existing RC slab bridges.

Empirical formula for the estimation of yield strength of steel by considering different parameters will be obtained. As verification, experimental results of an RC slab specimen and simulation of RC slab bridge with FEM were carried out.

2. RESTORATION DESIGN

In the restoration process, the effect of the test load and the instantaneous incremental deflection of the structure are taken into account. To obtain the maximum live load effect, the concept of influence line or the Green's function for RC beams is applied. For unknown effective depth, the flow to estimate effective depth and area of steel is shown in Figure 1.

Restoration design of RC slab bridges from deflection is discussed here under. To compute the deflection of the structure, the variation of the neutral axis depth and effective moment of inertia along the longitudinal axis needs to be computed based on the cracked and uncracked sections accordingly.

A general empirical formula for the estimation of the actual yield strength of steel using regression analysis with a correlation coefficient of 0.997 has been obtained (Tarekegn et al., 2012) and it is given in Eq. (1). The basic assumption considered in the estimation of actual yield strength of steel is that the flexural capacity of the section is estimated by considering the effect of yielding moment and stress- strain relationship is linear with tension steel only. Compressive strength of concrete, $f_c'^a$ (ranging from 24-32MPa) and E_s^a of 200Gpa are used. Since the test load is below the yield load, the bridge is considered as elastic and the moment is computed prior to yield point (below yielding). The input and output parameters in restoration design are shown in Figure 2 below.

$$f_y^a = -0.000215 m_d^2 + (0.000990 f_c'^a + 1.194) m_d + 7.956 \tag{1}$$

where: M^a - actual allowable flexural moment of the section (N-mm/m)

A_s^a - actual area of steel (mm^2/m)

f_y^a - actual yield strength of steel (MPa)

$f_c'^a$ - current concrete strength (MPa)

$m_d = M^a / A_s^a d^a$ (N/mm^2)

d^a- actual effective depth (mm)

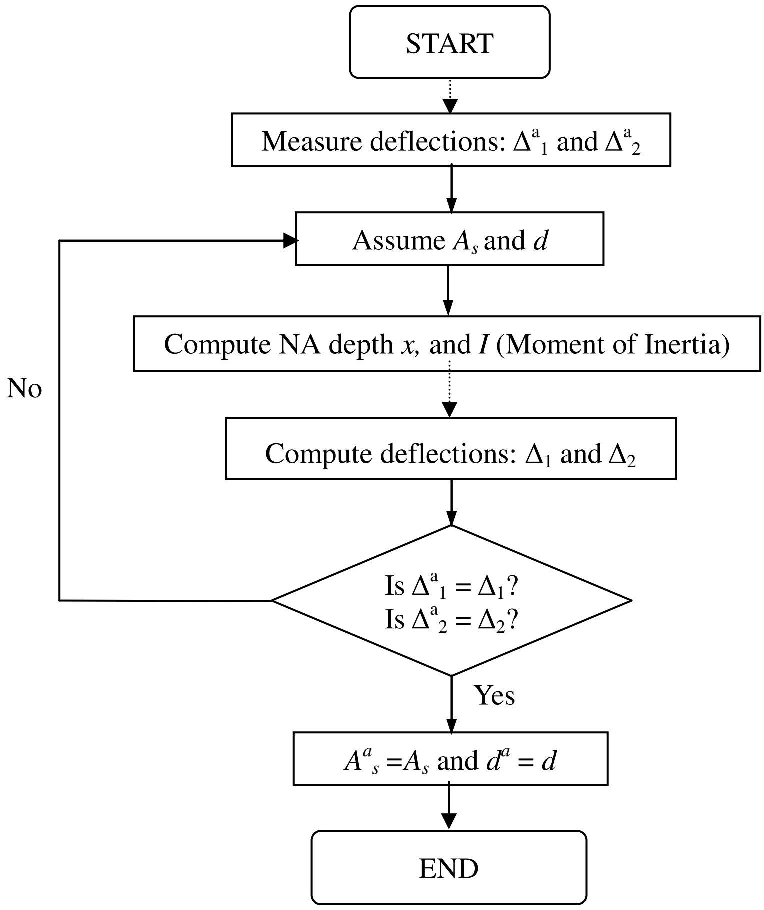

Figure 1. Flow of estimating effective depth and area of steel

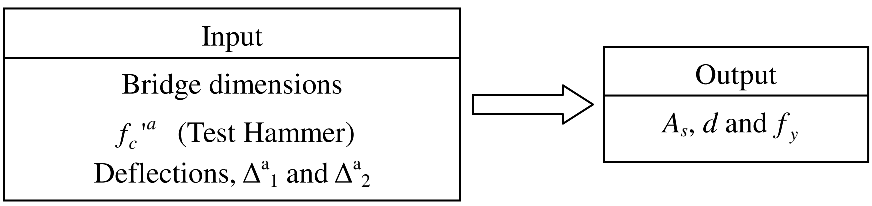

Figure 2. Input and output in restoration design

Based on the estimated value, the design value of f_y is selected from the nearest small discrete nominal value. The different discrete nominal yield strengths of steel (AASHTO, 2007) are shown in Table 1.

Table 1. Discrete nominal yield strength f_y

AASHTO M31 M Grade	Grade 300	Grade 420	Grade 520
Tensile strength, min. MPa	500	620	690
Yield strength, min. MPa	300	420	520

3. VERIFICATION OF RESULTS

3.1 Restoration design for experimental results

A test beam of RC slab with rectangular cross section of b x h= 600 x 200mm, with overall length of 2700mm and 2300mm distance between supports (Naganuma, 2012) is used to verify analytical results. Longitudinally, 8mm diameter deformed bars on both top and bottom surfaces with a spacing of 40mm were provided. The longitudinal cross section of the specimen is shown in Figure 3. Concrete with a 28 days characteristic compressive strength, f'_c, of 19.37MPa and steel bar with yield strength of 344MPa were used.

The specimen was simply supported at both ends and tested for two-point loading with loading points spaced at 400mm apart. The crack pattern and load-mid span deflection diagrams are shown in Figures 4 and 5 respectively.

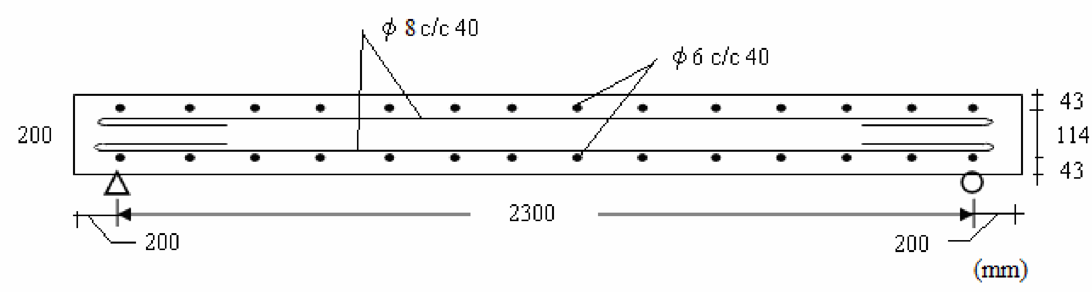

Figure 3. Longitudinal section of specimen

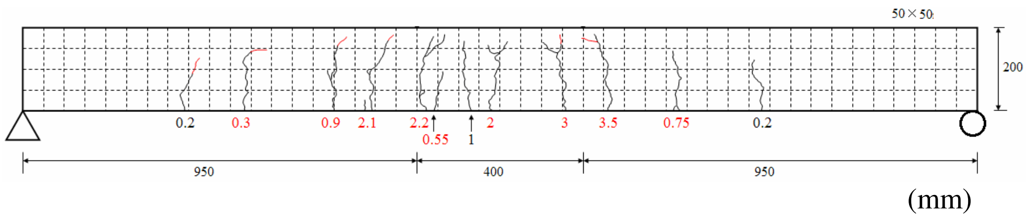

Figure 4. Crack pattern of the specimen

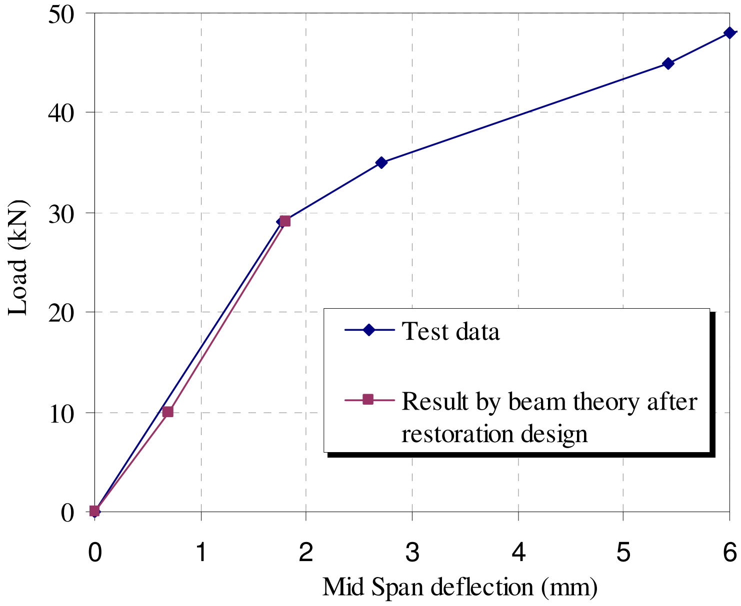

Figure 5. Load- mid span deflection diagram

For a particular load and mid-span deflection, within the elastic range, the area of steel reinforcement embedded in concrete and effective depth are obtained using a trial-and-error procedure and the results are shown in Table 2. The result shows a variation of -2.5% in the cross sectional area of steel and a -7.63% in the estimated actual yield strength of steel.

Table 2. Estimation of design data of RC specimen

Input parameters				(1) Restored values		(2) Initial values	(1)/(2)
P	29.00 kN	M^a	46.18 kN-m/m	A_s^a	1083.30 mm^2/m	1116.67 mm^2/m	0.97
W_k	0.27mm	E_s	200 GPa	d^a	159 mm	157 mm	1.01
Δ	1.77 mm	$f_c'^a$	19.37 MPa	f_y^a	317.77MPa	344MPa	0.92

Note: P-load, Δ-deflection, W_k -surface crack width

3.2 Restoration design for numerical model

A standard RC slab bridge of span length 10.40m is simulated using FEM (Figure 6). Different combinations of random variables are considered. In this case, allowable limits of measurements by AASHTO LRFD Bridge Construction Specification (AASHTO, 2002) were considered. Based on the results, incremental instantaneous mid-span deflection due to applied load, the actual area of reinforcing bar is computed. The input dimensions and material properties are shown in Table 3 below. The load- mid span deflection curve of the simulated bridge is shown in Figure 7.

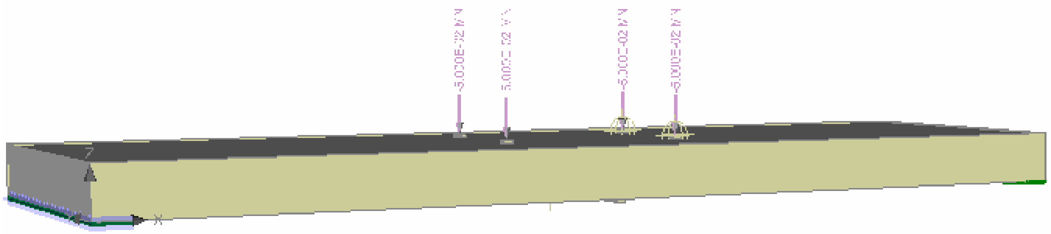

Figure 6. FEM model of RC slab bridge

In simulating the bridge, effective interior strip width is used. It is computed based on AASHTO LRFD Bridge Design Specification (AASHTO, 2007). For one and multiple lanes loaded, the effective interior strip widths are computed from Eqs. (2) and (3), respectively. Thus, the effective interior strip width of the bridge becomes the lesser of E_1 and E_m.

$$E_1 = 250 + 0.42\sqrt{SR} \tag{2}$$

$$E_m = 2100 + 0.12\sqrt{SR} \leq W / NL \tag{3}$$

where: S - modified span length taken equal to the lesser of actual span length or 18m
E_1 - interior strip width for one lane loaded
E_m - interior strip width for multiple lanes loaded
R - total roadway width (m) $\leq$ 9000mm
W- roadway width (m)
NL -Number of lanes loaded=W/3.6

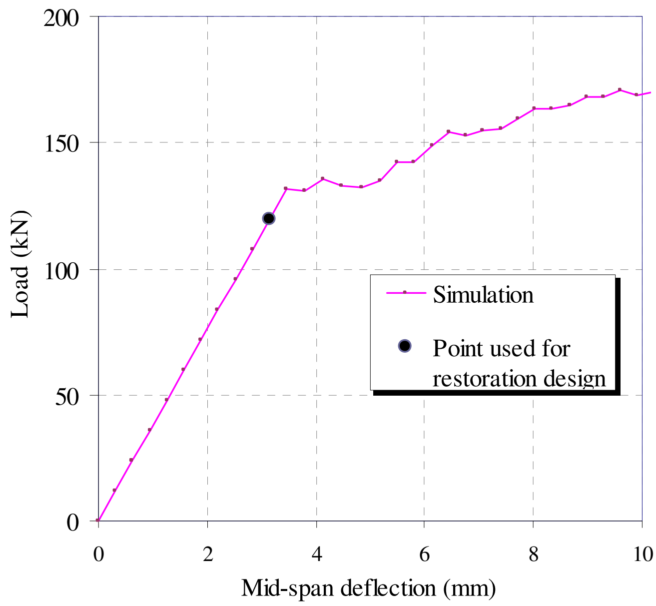

Figure 7. Load displacement diagram

Table 3. Standard RC slab bridge dimensions and material properties

Material properties	Bridge dimensions
f_y=400MPa f_c'=28MPa E_s=200GPa	Support dimension=0.40m c/c bridge spacing (S)= 10.4m Roadway width (W) = 7.32m Total roadway width (R) = 8.92m Load spacing =2.0m (longitudinal direction) and 1.2m (transversal direction) Effective strip width (E) = 3250mm Depth (D) =540mm, A_s=Φ32 c/c 180mm and d'=41mm

Based on the simulation results, the actual yield strength of steel is calculated using the regression equation given in Eq. (1). Table 4 below shows calculation results of the simulated bridge. A typical cross section of a standard RC slab bridge (ERA, 2002) is shown in Figure 8.

Table 4. Actual values of a 10m standard RC slab bridge

Input parameters				(1) Restored values		(2) Initial values	(1)/(2)
P	119.6kN	E_s	200 GPa	A_s	4618mm^2/m	4453mm^2/m	1.04
M^a	703.15kN-m/m	Strip width	3250mm	d	493mm	499mm	0.99
Δ	3.14 mm	$f_c'^a$	28 MPa	f_y^a	364.77MPa	400MPa	0.91

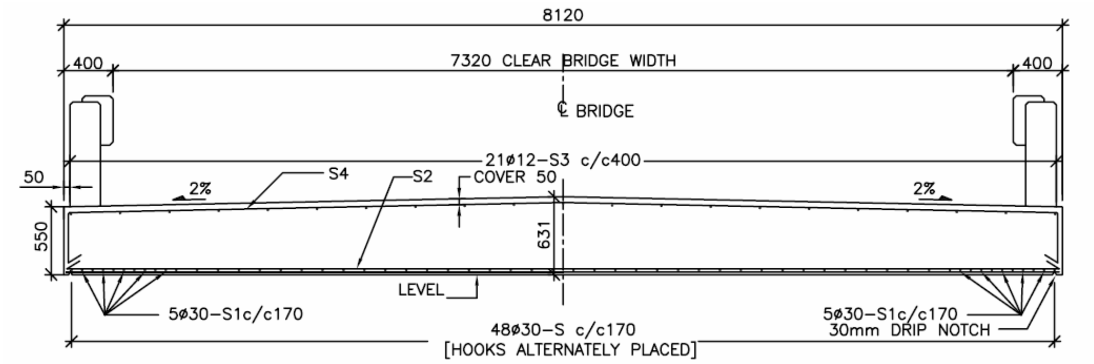

Figure 8. Typical cross section of a standard RC slab bridge

Using FEM, four standard bridges were simulated and the areas of steel, effective depth and actual yield strength of steel are estimated by restoration design process. $f_c'^a$ =28MPa and E_s=200GPa are used. Table 5 shows summary of results and restored design values.

Table 5. Summary of Input and restored data of standard RC slab bridges

Input parameters	Bridge span (m)	10	11	12	14
	Strip width (mm)	3250	3310	3360	3460
	Depth (mm)	540	580	620	700
	M^a (kN-m/m)	703.15	820.67	963.10	1299.00
(1) Restored values	A_s^a (mm^2/m)	4618	4721	5246	6283
	d^a (mm)	493	535	582	663
	f_y^a (MPa)	364.77	382.22	371.40	368.12
(2) Initial values	A_s (mm^2/m)	4453	4615	5022	6041
	d (mm)	499	539	579	659
	f_y (MPa)	400	400	400	400
Ratio (1)/(2)	A_s^a/A_s	1.04	1.02	1.05	1.04
	d^a/d	0.99	0.99	1.01	1.01
	f_y^a/f_y	0.91	0.96	0.93	0.92

4. CONCLUSIONS

(1) The empirical formula can be used for the estimation of actual yield strength of steel and is applicable for the whole range of typical RC slab bridges.

(2) A restoration design technique is presented to establish a methodology for the capacity performance assessment of existing RC slab bridges and can be computed by using restored design values.

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