Parametric Study on RC Bridge External Girder in 3D Finite Element Analysis

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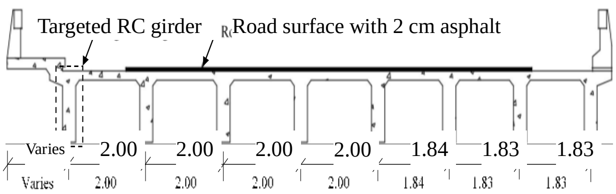
1. Introduction

At present, many countries have been facing with aging infrastructures, especially highway bridges. Those bridges have never been evaluated performances throughout their service lives. Furthermore, the effects of material degradation and the secondary members such as pedestrian way and parapet to the structural performance have never been considered.

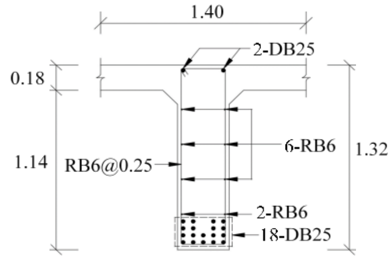
In this study, to clarify the effects of structural deterioration and to capture the effects of secondary members such as pedestrian way and parapet to structural behavior, the influences of secondary members to structural behavior of main girders will be firstly investigated through the parametric study using 3D Non-Linear Finite Element Method (3D NLFEM).

2. General description of targeted bridge

The bridge located in KhonKaen province, Thailand was used in this research. It consists of two types of superstructure: reinforced concrete girders (RC girders) and prestressed concrete girders (PC girders). However, the target of this research is aimed to perform parametric sensitivity study for the external RC girder. The typical girder was designed using the AASHTO standard specification. According to the bridge drawing, girder cross section is T-section with 15 meter span. Figure 1a and Figure 1b represent cross section of the targeted bridge and cross section of the targeted RC girder, respectively. It is important to note that the targeted RC girder is external RC girder.



(a)



(b)

Figure1: (a) Cross section of the bridge; (b) Cross section of RC girder

The RC girder has a cross sectional area of 0.685 m^2, a moment of inertia of 0.116 m^4 and a center of gravity 0.83 m. from its base.

The pedestrian way and parapet on the targeted bridge are the standard type used in Thailand highway bridges. The cross section of the pedestrian way and parapet are presented in Fig.2, and the girder sectional properties after combine with pedestrian way and parapet are tabulated in Table 1

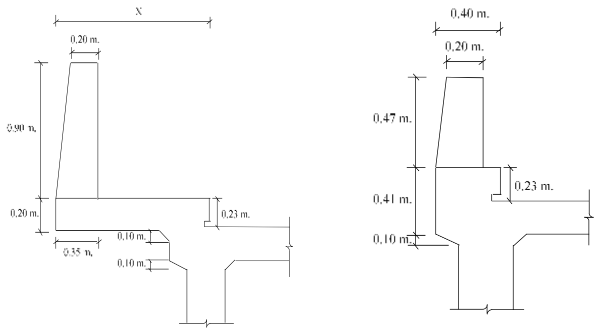


Figure 2 Parapet and pedestrian way width 1.50 m., 1.00 m and 0.40 m.

Note: X is equal to 1.50 m. and 1.00 m.

Table 1 Girder sectional properties

Type	A (m^2)	I (m^4)	C.G. (m.)
Parapet with pedestrian way width 1.50 m.	1.296	0.399	1.234

Parapet with pedestrian way width 1.00 m.	1.185	0.393	1.214
Parapet with pedestrian way width 0.40 m.	0.843	0.219	1.000

Note: A is cross sectional area (m^2), I is moment of inertia about x axis (m^4), C.G. is center of gravity measured from its base.

The material properties used in this research are shown in Table 2. For concrete, the compressive strength was obtained from non-destructive test using rebound Schmidt's hammer test. The value obtained from the test was measured base on standard cylinder test[1)]. For steel reinforcement, the properties were obtained from the bridge drawing and specification. In this research, the material properties of RC girder, parapet and pedestrian way are postulated to be the same value.

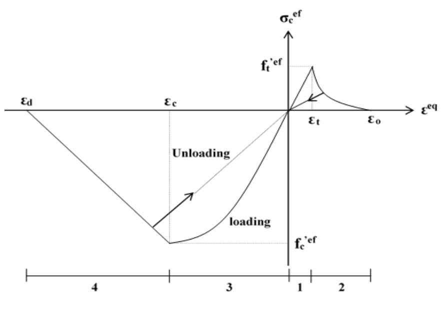
Table 2 Materials properties

Concrete		*Reinforcement*	
f_c'(MPa)	*E_c (MPa)*	*Ø (mm.)*	*f_y (MPa)*
11.8	21,530	≥12	276
		<12	228

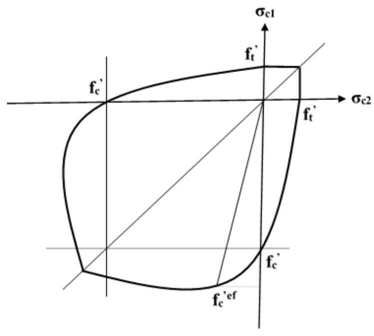
Note: f_c'= compressive strength of concrete (cylinder), E_c= elastic modulus of concrete, *ø*= reinforcement diameter, f_y= yielding strength of steel reinforcement.

3. 3D Non-Linear Finite Element Method (3D NLFEM)

In this research, the commercial 3D ATENA program was implemented to perform numerical analysis. For concrete, the equivalent uniaxial stress-strain laws and biaxial stress failure criterion are implemented to describe the behavior of concrete. The number 1, 2, 3 and 4 in Figure 4a express the behavior of concrete in each state: tension before cracking, tension after cracking, compression before peak stress and compression after peak stress[2)]. These two laws are illustrated in Fig.3. The smeared approach is obtained to model cracks happening in concrete. In this research, the fixed crack model is applied in which cracks direction is governed by the principal stress direction at the cracks initiation. This direction is fixed during load increment, and it represents the material axis[2)]. Figure 4 illustrates the fixed cracked model and stress-strain state.



(a)



(b)

Figure 3: (a) Equivalent uniaxial stress-strain laws, (b) Biaxial stress failure criterion

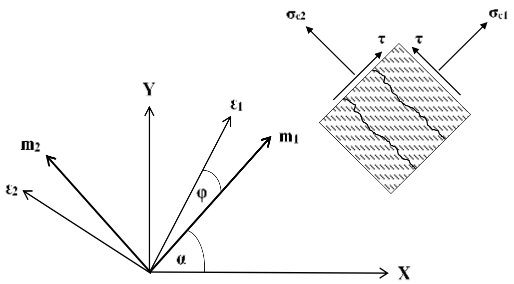


Figure 4 Fixed cracked model and stress-strain state

For steel reinforcement, the bi-linear stress-strain law was applied in the numerical model to simulate the reinforcing bar. The elastic modulus of steel (E_s) is applied in the first part. Then, the perfect plasticity of which the hardening modulus (E_{sh}) is zero is utilized in the second part. The main reinforcing steel was modeled using discrete element, whereas the stirrup was modeled using smeared reinforcement. The perfect bond between concrete and reinforcing bar was utilized[2)]. Figure 5 expresses the bi-linear stress-strain laws of reinforcement

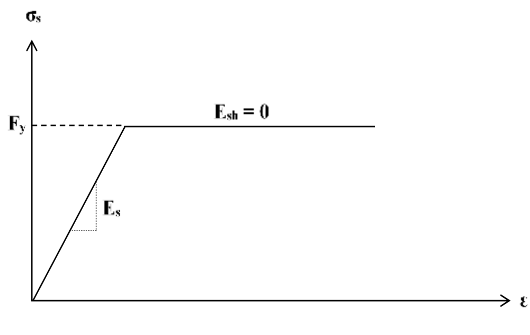


Figure 5 Bi-linear stress-strain laws of reinforcement

Since the symmetrical geometry of the RC girder, it was modeled using half of the span. Accordingly, to define the symmetry of the RC girder, the x-restraint had to be specified at the midspan, and the RC girder is simply support girder. Figure 6 illustrates the 3D numerical model used in the analysis.

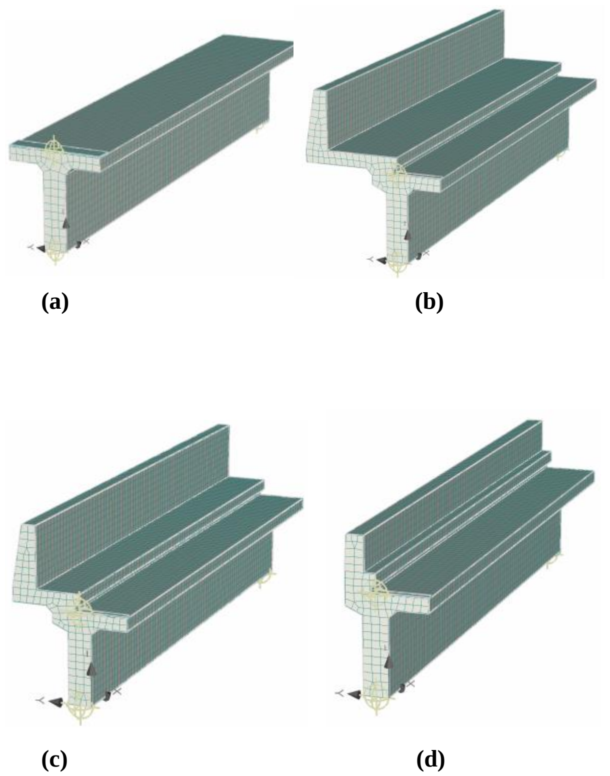


Figure 6 3D numerical model: (a) Typical RC girder, (b) RC girder with parapet and pedestrian way width 1.50 m, (c) RC girder with parapet and pedestrian way width 1.00 m, (c) RC girder with parapet and pedestrian way width 0.40 m

For the loading condition, the prescribed deformation was utilized to apply three-point bending monotonic load. Furthermore, to capture the response of the RC girder during analysis, the monitoring point was specified at loading point, midspan, and support. The Newton-Raphson iterative procedure was conducted to perform the nonlinear calculation.

4. Analytical results and discussion

To study the behavior of RC girders, the parametric study was performed considering material properties with and without and effects of pedestrian way and parapet. The parameters were summarized in Table 3.

Table 3 Parameters used in the study

Case	$f_c^{'}$ *(MPa)*	E_c *(MPa)*	Parapet and pedestrian way width (m)
1	11.8	21,530	Not included
2	25	29,890	Not included
3	11.8	21,530	1.50
4	11.8	21,530	1.00
5	11.8	21,530	0.40

Case 1 represents the current state of the typical RC girder according to non-destructive test results. On the other hand, case 2 is analyzed to express the designed state behavior of the targeted RC girder. For case 3, case 4 and case 5, the analysis is performed to investigate the influence of secondary members to the typical RC girder's behavior.

4.1 Load-vertical displacement relations

The analysis results are represented as the total load-vertical displacement relation shown in Figure 7. Then, the percent difference between ultimate loads and stiffness in each case is tabulated in Table 4.

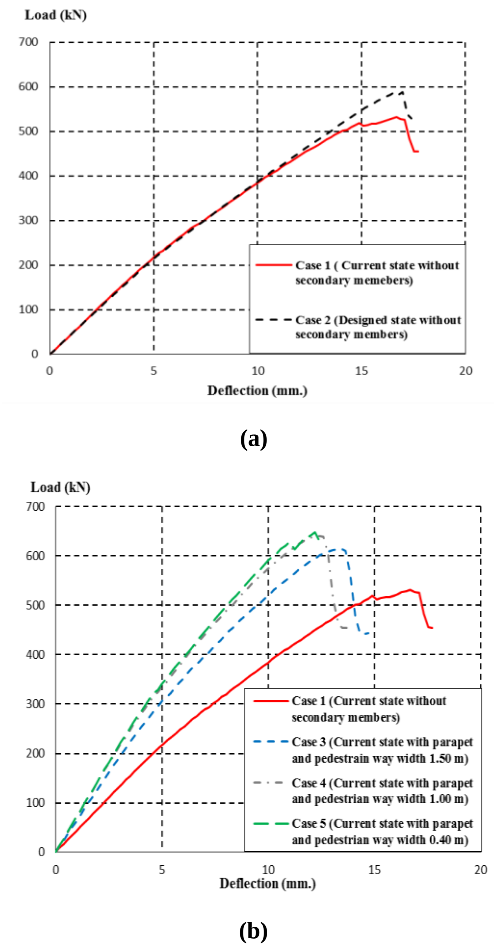


Figure 7: (a) Comparison of total load-vertical displacement between case 1 and case 2, (b) Comparison of total load-vertical displacement between case 1, case 3, case 4 and case 5

According to the Table 4, the analysis results show that ultimate load capacity of the RC girder may be between 530 kN and 650 kN. This indicates that both compressive strength and secondary members are not strongly influent to the ultimate load of the RC girder. For the stiffness, according to Fig. 7(a), the stiffness between case 1 and case 2 are not significantly different. Therefore, stiffness of the RC girder is not sensitive with changed concrete strength. On the other hand, the secondary members such as parapets and pedestrian way influence to stiffness of the RC girders obviously. The increasing of the RC girder stiffness can be observed in Fig. 7(b) since the contribution between RC girder and secondary members. It is important to note that the stiffness shown in Table 4 is a linear stiffness before cracking.

Table 4 Percent difference between ultimate loads and stiffness in each case

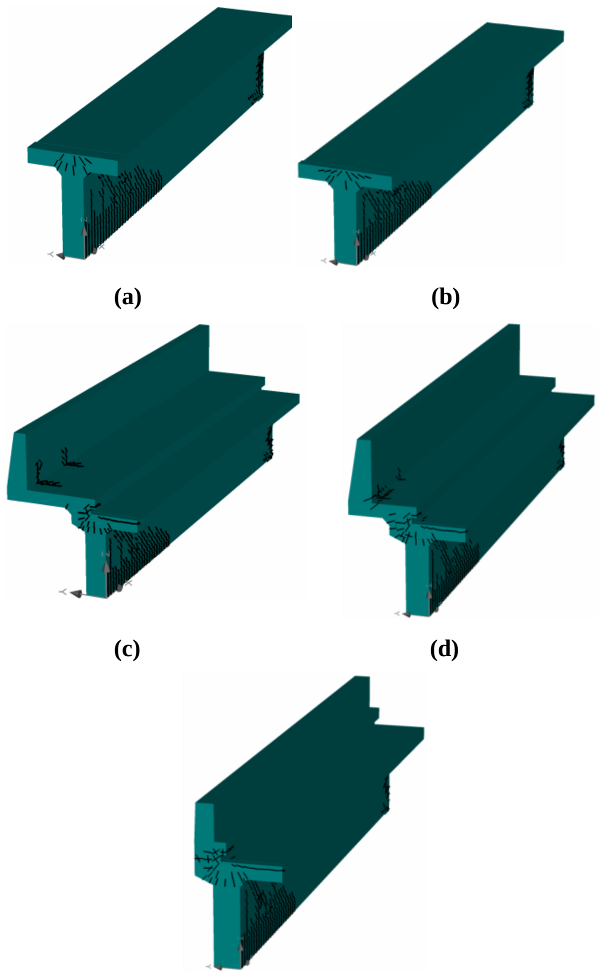
Case	P_u (kN)	k (kN/m)	N.A. (m)	Ratio of P_u	Ratio of k	Ratio of N.A.
1	532	44	0.83	1.0	1.0	1.0
2	588	44	0.83	1.1	1.0	1.0
3	614	65	1.23	1.2	1.5	1.5
4	641	72	1.21	1.2	1.6	1.5
5	648	73	1.00	1.2	1.7	1.2

Note: P_u = ultimate load capacity, k = stiffness, N.A. = neutral axis.

Ratio = interested value in other case/value in case1

4.2 Failure modes

For the failure mode at the ultimate load capacity, shear failure was happened in all cases. Figure 8 shows the crack pattern happening on the RC girder.



(a) (b) (c) (d) (f)

Figure 8: Crack pattern at ultimate load capacity in each case

Note: (a) = case 1, (b) = case 2, (c) = case 3, (d) = case 4, (f) = case 5

Table 5 illustrates the ultimate load capacity obtained from the design equations provided by the AASHTO LRFD bridge design specification[3)] and 3D FEM

Table 5 Ultimate load capacity

$P_{u,\ moment}$ (kN)	$P_{u,\ shear}$ (kN)	$P_{u,\ 3D\ FEM}$ (kN)	Ratio of $P_{u,3D\ FEM}$ and $P_{u,shear}$
647	492	532	**1.08**

Note: $P_{u,\ moment}$ = ultimate load obtained from flexural design equation, $P_{u,\ shear}$ = ultimate load obtained from shear design equation, $P_{u,\ 3D\ FEM}$ = ultimate load capacity obtained from 3D FEM.

Ratio = interested $P_u/P_{u,\ shear}$

According to Table 5, the ultimate load capacity obtained from shear design equation[3)] is less than that obtained from moment design equation and 3D FEM. Furthermore, the ultimate load capacity obtained from 3D FEM is less than that obtained from moment design equation. Finally shear damage is happened at ultimate load capacity

5. Conclusion

(1) The secondary members provide greater influence to the stiffness of the RC girder rather than the concrete compressive strength.

(2) Shear damage happens at the ultimate load in the analysis. The ultimate load obtained from 3D FEM is slightly greater than the load obtained from recent shear design equation.

6. Reference

1) ACI (American Concrete Institute). (2008) "*Building Code Requirement for Structural Concrete (ACI318M-08) and Commentary*", 1st Edition. American Concrete Institute, Farmington Hills, MI, USA.

2) Vladimir Cervenka, Libor Jendele, and Jan Cervenka (2016). "*ATENA Program Documentation, Theory*" Cervenka Consulting. Prague, Czesh Republic.

3.) AASHTO (American Associate of State Highway and Transportation officials). (2012) "*AASHTO LRFD Bridge design specification, Customary U.S. Units*", 6th Edition. AASHTO, Washington, D.C.