LOADING TEST ON THE RENOVATED THAI-BELGIAN BRIDGE IN BANGKOK

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ABSTRACT

This paper is concerned with static and dynamic loading of the renovated Thai-Belgian bridge located in Bangkok. The tests on the renovated Thai-Belgian bridge are performed in order to guarantee the safety of the bridge. In the static test, the real Thai trucks in static conditions are applied to the bridge. The responses are measured at critical points of the bridge in terms of static strain and deflection. Based on the current design practice, the analysis of the bridge is performed, and the calculated results are compared with the measured ones. The safety of the bridge is checked by comparing the measured values and the allowable values specified in the design specification. In addition, in order to assess vibrational serviceability of the bridge the dynamic test is performed by running the Thai truck with different speeds and measuring the acceleration of the bridge, and the maximum responses are compared with the acceptable values.

1. INTRODUCTION

In general, the loading test of an important structure should be performed before opening for its usage to confirm that it will perform satisfactorily. This requirement becomes especially critical if the structure is renovated one due to the possible reduction in the stiffness of the existing structure. [1]

The renovated Thai-Belgian bridge is located in the intersection between Witthayu-Sathorn road and Rama IV road in the central part of Bangkok. The overall length of the bridge is about 300m with the longest simply supported span of 29.55 m. As shown in Fig. 1, the bridge consists of 5 composite steel-concrete girders with distance of 1.55 m between each of them. The steel girder is a hybrid structure with yield stress of web of 35 psi and that of bottom flange of 50 psi. The height of the girder is 0.86m with 0.175m concrete on top.

The two materials are connected by stud shear connector with shear capacity of 11.44 t/stud. The renovated bridge is designed by following the AASHTO specification, namely ASD method [1].

The scope of this paper is to check the safety and the serviceability of the renovated Thai-Belgian bridge under both static and dynamic truck loading. In static case, the measured stress and deflection are compared with the calculated values, which are obtained by using the same analytical method as in the current design practice. For the dynamic case, the acceleration responses are measured under moving truck loads. Finally, the measured values are checked with allowable ones in terms of stress, deflection, acceleration and velocity.

2. STATIC TEST

In this study, the so-called Thai truck in Fig. 2 weighing 31.4 tons, specified in Thai design code as design truck load, is used for the static test. The truck is placed at the critical positions of the bridge which are determined by the influence line analysis. Three load cases are used to determine the behavior of the bridge namely, 1 truck loading, 3 truck loading and 6 truck loading. Vibrating wire strain gauges and laser telescope are used to measure the strain and the deflection respectively.

2.1 Test Procedure

Four stages are considered in the present measurement, namely

Stage 0 (Initial): When the erection of steel girder is just completed, the bare steel girder carries only its own weight.

Stage 1: When there is only concrete slab load acting on the steel girder, the bare steel girder carries the steel and concrete slab load.

Stage 2: When there are concrete slab load and superimposed dead load i.e. barrier and asphalt surface on the concrete slab, these loads are carried by the composite action of the girder since the concrete is already hardened.

Stage 3: when the bridge is under truck loading test or subjected to the previous dead and superimposed dead loads and live loads (truck load), the girder acts as composite structure.

The strains are measured at the above stages 0, 1, 2 and 3, however due to technical problems at the construction site, the deflection is measured only at stages 2 and 3.

In this test 15 strain gauges are installed in different location. The positions of the gauges are listed below:

- strain gauge no. 1-8 at top and bottom flange of girders G1 and G2
- strain gauge no. 9-11 at bottom flange of girders G3, G4 and G5
- strain gauge no. 12-13 at bottom flange of girders G1 at 1/4 and 3/4 of span
- strain gauge no. 14 at cross girder
- strain gauge no. 15 at column.

The positions of the strain gauges are shown in Figs. 1 and 3. These strain gauges and deflection-measured points are determined to give necessary information of the bridge and are based on previous experience in the similar kind of test.

In order to measure stresses and deflection in the longitudinal girder, cross girder and column, the trucks are placed on the 30m middle spans of the Thai-Belgian bridge between pier P6 and P8. For longitudinal girders, 1 and 3 trucks are placed between pier P6 and P7 at the critical positions where the maximum bending moment in the longitudinal girder occurs. The positions of the trucks for the 1-truck and 3-truck cases are shown in Figs. 4 and 5, respectively. For cross girder and column, 6 trucks are placed between pier P6 and P8. In this case, the critical position of the truck is chosen to give the maximum bending moment in the cross girder. The location of the 6-truck case is shown in Fig. 6.

In the measurement of stress and deflection at stage 3, three-time reading is made for each of the three loading cases to obtain the average values.

2.2 Comparison between Measured and Calculated Results

From static test results in case of only live loads shown in Tables 1 and 2 (taken from the difference between stage 3 and 2 in section 2.1), most of the measured values are less than the calculated values, which are obtained by using the current design practice, except in girders G3, G4 and G5. In these girders, the measured values are greater than the calculated ones because of the difference in the truck load distribution. In the calculation, the girders G4 and G5 are assumed not to carry any load at all and the load distribution to girder G3 is underestimated.

However, while comparing with the case of combined concrete slab, barrier/asphalt and live loads as shown in Tables 3 and 4 (taken from the sum of differences between stage 1 and 0, stage 2 and 1, stage 3 and 2 in section 2.1), the measured values are higher only in girder G3. Probably, the weight of concrete slab on girder G3 is underestimated in the calculation due to excessive cambering of girder G3 during fabrication.

In the summary of results shown above, the calculated values in most cases are greater than the measured values. Hence, in terms of stress, it can be concluded that the design is on the safe side. For girder G3, even though the measured value is higher than the calculated one, the difference of about 10% might be acceptable.

The above-mentioned differences between the measured and calculated values are due to the assumption used in the design. In the design, simplified model is used, i.e. composite model using stiffness of concrete only in the effective width and neglecting the stiffening element. From the measured stress, the neutral axis can be calculated as:

$$y_t = \frac{\sigma_t}{(\sigma_t + \sigma_b)} \bullet h$$

where y_t = distance from the top extreme fiber to the neutral axis

σ_t , σ_b = normal stress in the top flange and bottom flange, respectively

h = height of the I-beam.

For example, in the girder G1, subjected to only live loads, y_t, calculated from the measured stress, is 13.8 cm. However, the y_t value, which is calculated by the current design method, is 47.9 cm. This difference in the location of the neutral axis can be used to support the reason for the vast difference in the measured and calculated values as mentioned above. More complicated analysis using finite element methods is required to give more accurate results. The appropriate finite element modeling of the composite steel-concrete girder will be reported in the near future.

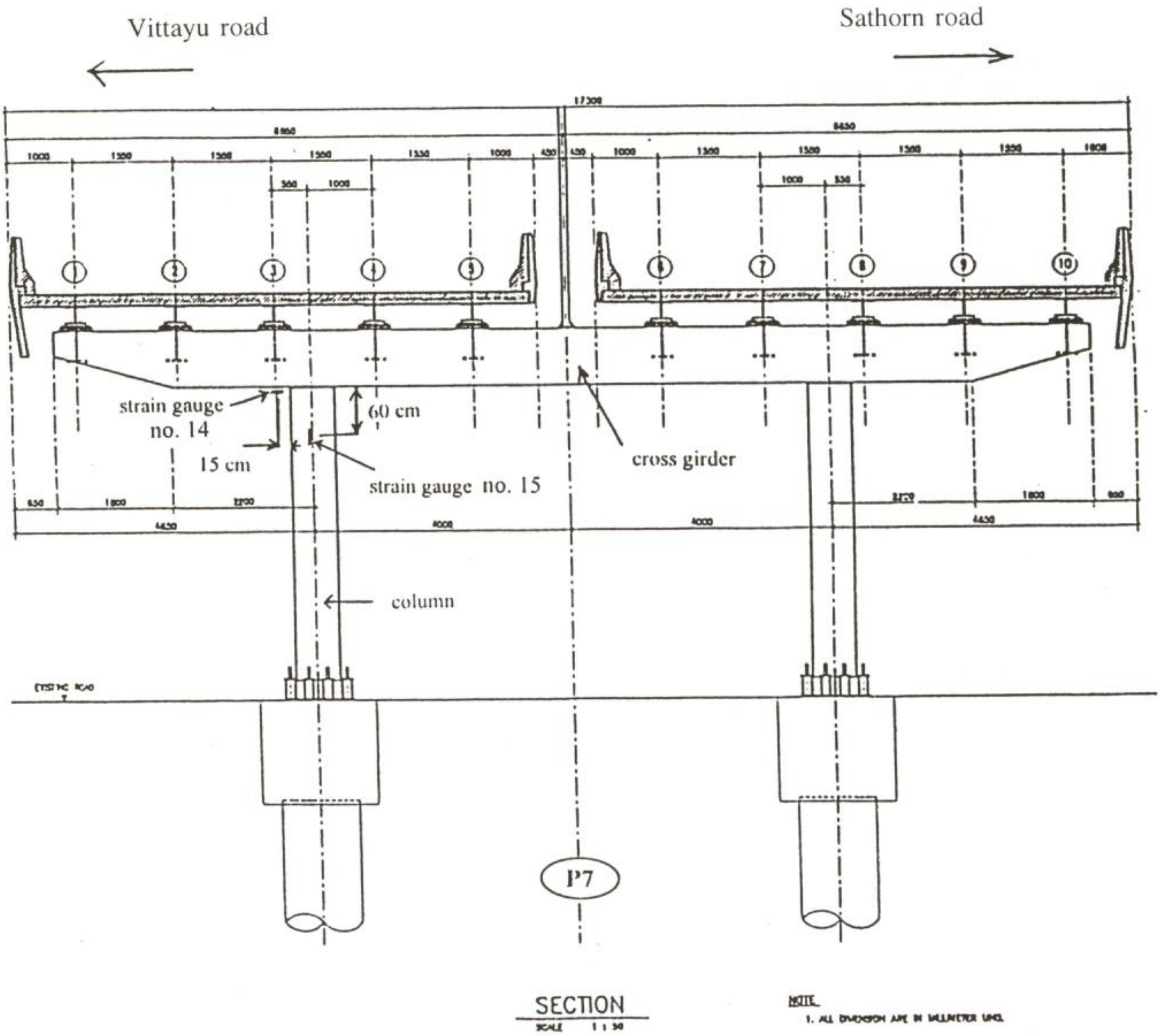


Fig. 1 Cross-section of Thai-Belgian bridge

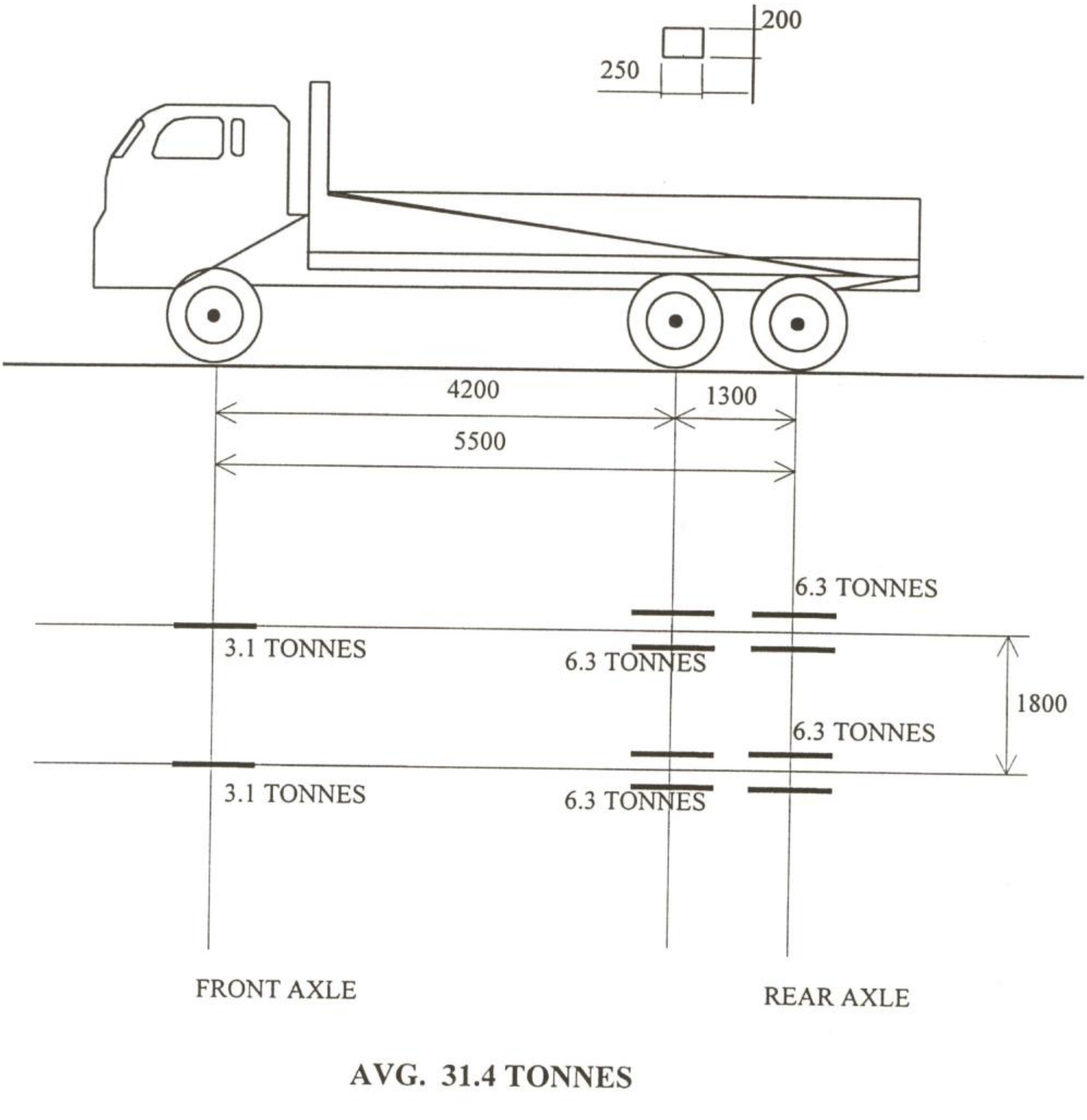


Fig. 2 Thai truck model

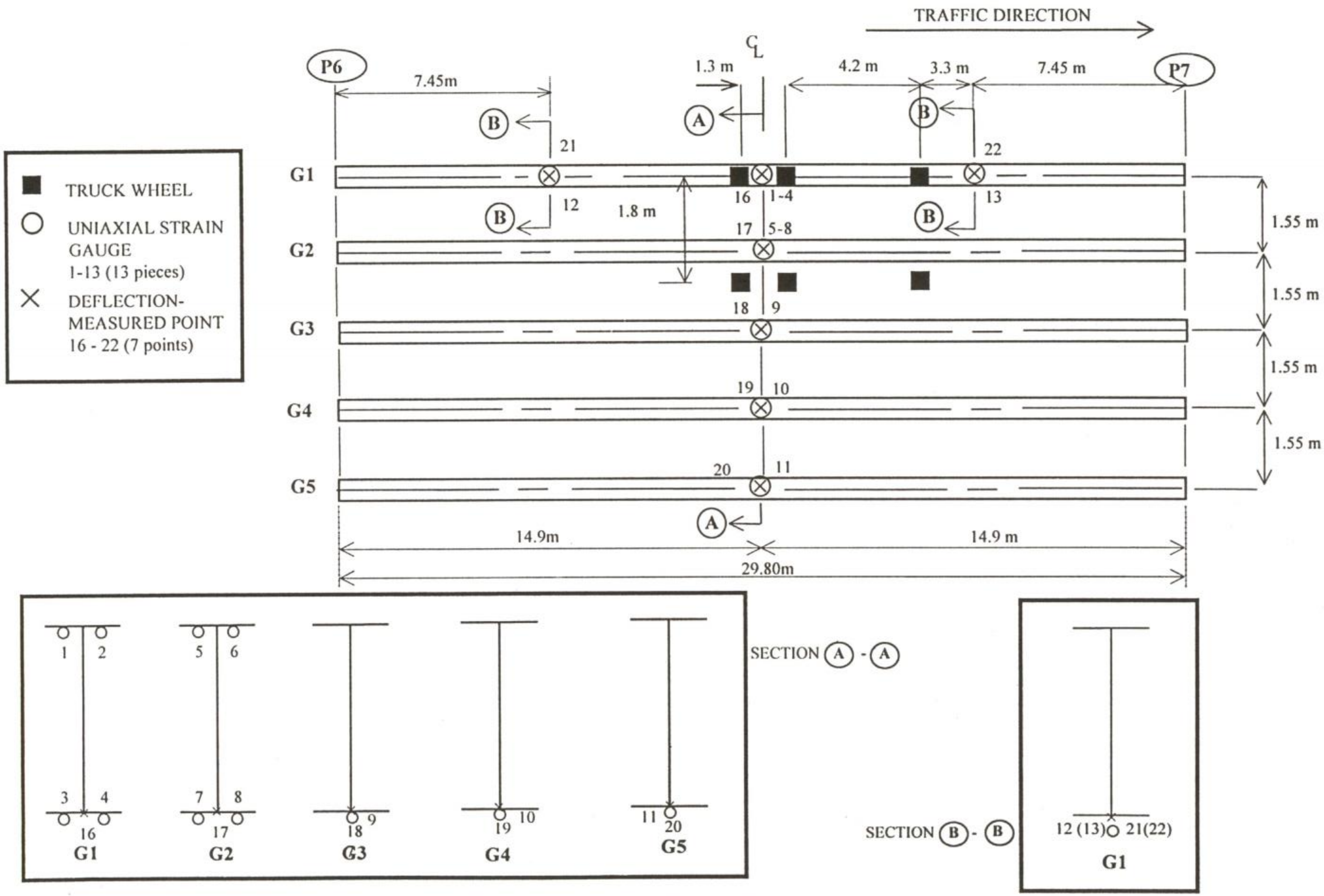


Fig. 3 Positions of strain gauges and deflection-measured points

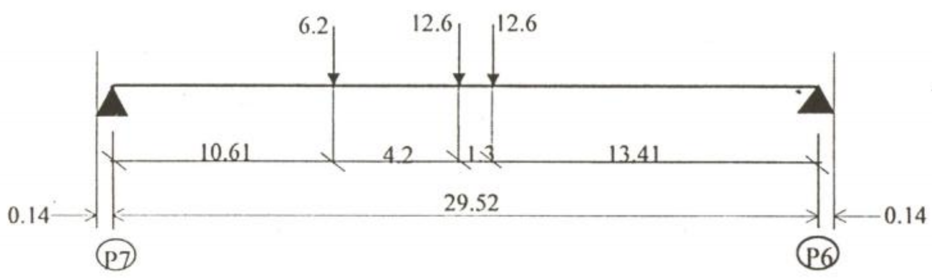


Fig. 4 One-truck loading

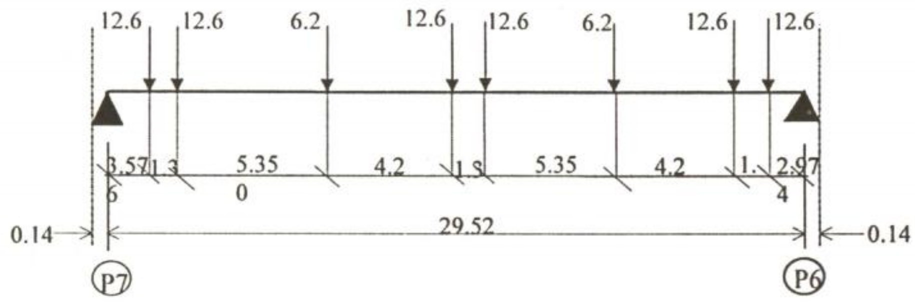


Fig. 5 Three-truck loading

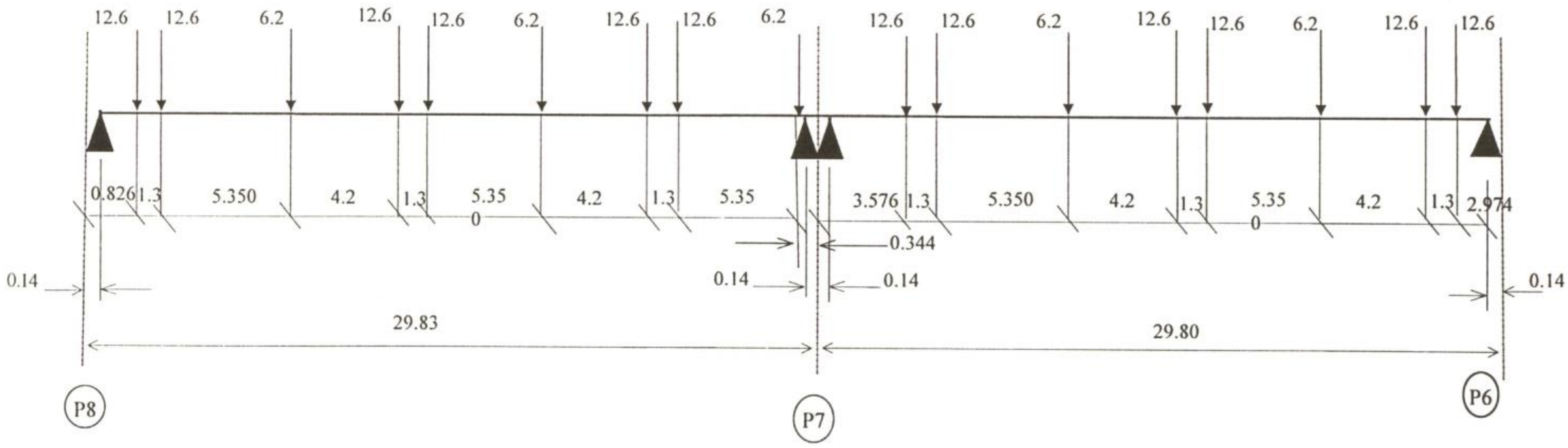


Fig. 6 Six-truck loading

Table 1 Comparison for 30-meter longitudinal girder for 1-truck load (only live loads)

(a) Stress

Girder	Distance from P7	Location	Gauge number	Measured stress (ksc)	Calculated stress (ksc)	Difference (%)
exterior girder G1	15 m.	top flange	1,2	58.92	169	186.83
	15 m.	bottom flange	3,4	304.28	436	43.29
	7.5 m.	bottom flange	12	162.52	399	145.51
	22.5 m.	bottom flange	13	183.44	399	117.51
interior girder G2	15 m.	top flange	5,6	56.30	165	193.07
	15 m.	bottom flange	7,8	219.80	426	93.81
interior girder G3	15 m.	bottom flange	9	152.34	77	-49.46
interior girder G4	15 m.	bottom flange	10	28.78	0	-100.00
exterior girder G5	15 m.	bottom flange	11	5.43	0	-100.00

(b) Deflection

Girder	Distance from P7	Location	Gauge number	Measured deflection (cm)	Calculated deflection (cm)	Difference (%)
exterior girder G1	15 m.	bottom flange	16	1.90	2.57	35.26
	22.5 m.	bottom flange	21	1.50	1.88	25.33
	7.5 m.	bottom flange	22	1.70	1.94	14.12
interior girder G2	15 m.	bottom flange	17	1.50	2.51	67.33
interior girder G3	15 m.	bottom flange	18	0.80	0.45	-43.75
interior girder G4	15 m.	bottom flange	19	0.50	0.00	-100.00
exterior girder G5	15 m.	bottom flange	20	0.10	0.00	-100.00

Table 2 Comparison for 30-meter longitudinal girder for 3-truck load (only live loads)

(a) Stress

Girder	Distance from P7	Location	Gauge Number	Measured stress (ksc)	Calculated stress (ksc)	Difference (%)
exterior girder G1	15 m.	top flange	1,2	55.66	269	383.29
	15 m.	bottom flange	3,4	446.99	694	55.26
	7.5 m.	bottom flange	12	339.93	627	84.45
	22.5 m.	bottom flange	13	316.81	627	97.91
interior girder G2	15 m.	top flange	5,6	64.16	262	308.35
	15 m.	bottom flange	7,8	329.32	676	105.27
interior girder G3	15 m.	bottom flange	9	242.43	123	-49.26
interior girder G4	15 m.	bottom flange	10	117.69	0	-100.00
exterior girder G5	15 m.	bottom flange	11	15.07	0	-100.00

(b) Deflection

Girder	Distance from P7	Location	Gauge Number	Measured deflection (cm)	Calculated deflection (cm)	Difference (%)
exterior girder G1	15 m.	bottom flange	16	3.35	4.60	37.31
	22.5 m.	bottom flange	21	2.60	3.49	34.23
	7.5 m.	bottom flange	22	2.70	3.59	32.96
interior girder G2	7.5 m.	bottom flange	17	2.45	4.48	82.86
interior girder G3	15 m.	bottom flange	18	1.70	0.81	-52.35
interior girder G4	15 m.	bottom flange	19	0.80	0.00	-100.00
exterior girder G5	15 m.	bottom flange	20	0.15	0.00	-100.00

Table 3 Comparison for 30-meter longitudinal girder for 1-truck load (concrete slab, barrier and live loads)

Girder	Distance from P7	Location	Gauge Number	Measured stress (ksc)				Calculated stress (ksc)	Difference (%)
				concrete	barrier	live load	total		
exterior girder G1	15 m.	top flange	1,2	718	233.79	58.92	1010.71	1154	14.18
	15 m.	bottom flange	3,4	468	382.18	304.28	1154.76	1304	12.95
	7.5 m.	bottom flange	12	388	298.24	162.52	848.76	1212	42.80
	22.5 m.	bottom flange	13	374	289.18	183.44	846.62	1212	43.16
interior girder G2	15 m.	top flange	5,6	692	258.35	56.30	1006.65	1092	8.48
	15 m.	bottom flange	7,8	346	343.02	219.80	908.82	1233	35.67
interior girder G3	15 m.	bottom flange	9	464	334.60	152.34	950.94	884	-7.04
interior girder G4	15 m.	bottom flange	10	314	312.78	57.56	684.34	807	17.92
exterior girder G5	15 m.	bottom flange	11	404	215.45	5.43	624.88	868	38.91

Table 4 Comparison for 30-meter longitudinal girder for 3-truck load (concrete slab, barrier and live loads)

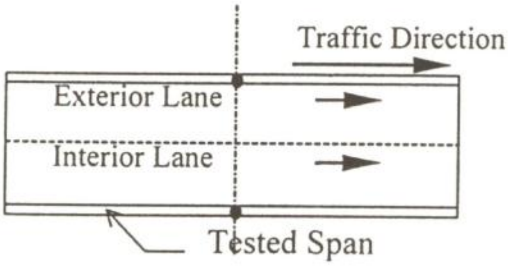
Girder	Distance from P7	Location	Gauge Number	Measured stress (ksc)				Calculated stress (ksc)	Difference (%)
				concrete	barrier	live load	total		
exterior girder G1	15 m.	top flange	1,2	718	233.79	55.66	1007.45	1254	24.47
	15 m.	bottom flange	3,4	468	382.18	447.00	1297.17	1562	20.42
	7.5 m.	bottom flange	12	388	298.24	339.93	1026.17	1403	36.72
	22.5 m.	bottom flange	13	374	289.18	316.81	979.99	1403	43.16
interior girder G2	15 m.	top flange	5,6	692	258.35	64.16	1014.51	1189	17.20
	15 m.	bottom flange	7,8	346	343.02	329.32	1018.34	1483	45.63
interior girder G3	15 m.	bottom flange	9	464	334.60	242.43	1041.03	930	-10.67
interior girder G4	15 m.	bottom flange	10	314	312.78	117.69	744.47	807	8.40
exterior girder G5	15 m.	bottom flange	11	404	215.45	15.07	634.52	868	36.80

Table 5 Comparison between measured and allowable stress in AASHTO

Location	Girder/Column	Flange	Measured stress (ksc)	Allowable stress (ksc)
Mid-span between P6 and P7	Longitudinal girder, G1	Top	1345	1934
		Bottom	1492	1934
at P6	Cross girder	Bottom	865	1934
	Column		592	1516

2.3 Comparison between the Measured and Allowable Values Specified in the Code

Table 5 shows the measured stress and the allowable stress in AASHTO. The measured value is less than the allowable value in all components. Hence, in the critical case of three-truck and six-truck loading, the bridge is safe in terms of the strength of main structural components.



• Position of Accelerometer

Fig. 7 30-m tested span

3. DYNAMIC TEST

3.1 Test Procedure

In the dynamic test, the 21-ton Thai truck is running in the middle 30-m span, and the vertical acceleration responses are obtained under truck velocity of 5, 10, 15, 20, 30, and 40 km/hr by using 2 low-frequency accelerometers on the left and right sides of the traffic lane. The accelerometers give the acceleration data of the bridge which can be integrated to obtain velocity for the assessment of vibrational serviceability of the bridge. The positions of the accelerometer are shown in Fig. 7.

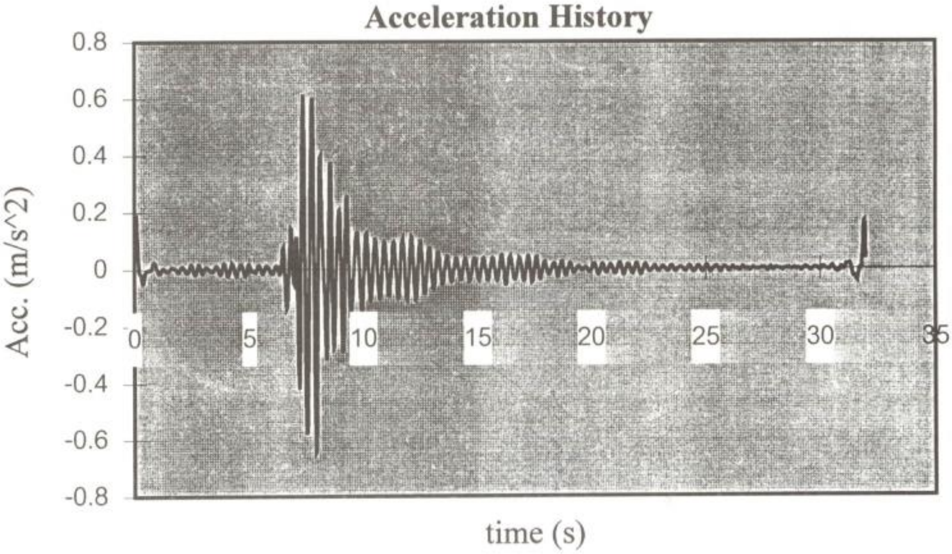
For each vehicle speed, the measurement of both accelerations on left and right sides is made when the truck runs in either exterior lane or interior lane, and two-time reading is done to obtain the average values.

3.2 Analysis of Tested Data

Two numerical techniques, namely numerical integration by Trapezoidal rule and bandpass filter, are used to analyze the raw tested data. For many structural dynamic data, the need often arises for evaluating the definite integral of a function that has no explicit antiderivative or whose antiderivative is not easily obtained. In this study, Trapezoidal rule [2] is used to integrate acceleration in order to obtain velocity because it will not lose data upon integration. Bandpass filter is used in this paper to purify the raw data from contamination by unwanted noise like high frequency electronic noise or low frequency thermal drift [3]. Examples of acceleration and velocity obtained by applying the above two numerical techniques to the raw data are shown in Fig. 8

3.3 Discussion of Results

The peak acceleration and velocity for each truck speed are shown in Table 6. It is noted that the peak acceleration and velocity do not increase with the increase in truck speed, and vice versa. It was reported that the acceleration of less than 0.1g (or 0.98 m/s^2)



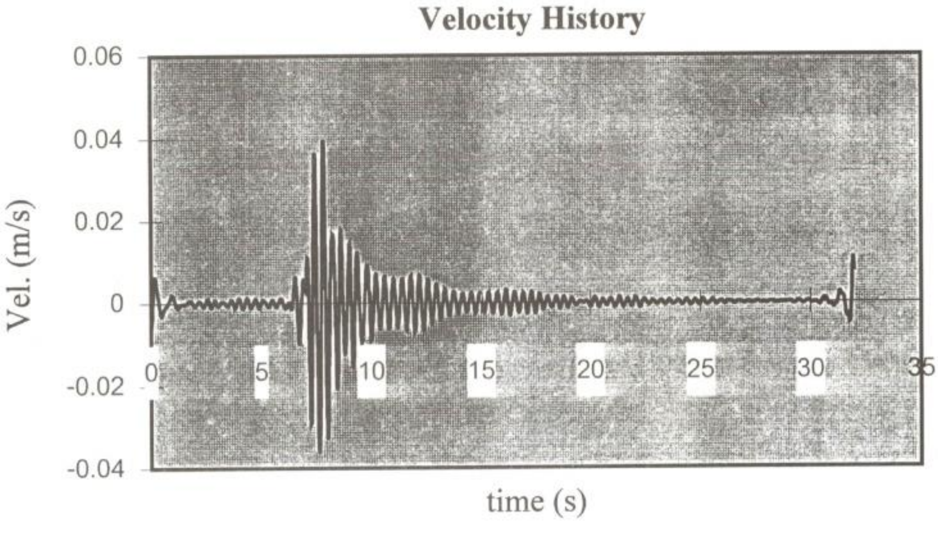


Fig. 8 Acceleration and velocity history of the bridge for truck speed of 40 km/hr

gave an uncomfortable feeling to the users on structures [4]. The peak acceleration in Table 6 is below this acceptable value, and hence the serviceability of bridge against vibration is confirmed.

Another comparison to assess this serviceability can be made in terms of peak velocity. Table 7 shows the serviceability limit of pedestrian bridge [5]. When the above data is compared with the measured velocity in Table 6, it can be seen that the results fall in category 3. Though there might be slight walking difficulty for the users of the bridge, one should keep in mind that the renovated Thai-Belgian bridge is not a pedestrian bridge. The users of the bridge might not feel too much discomfort because the users are driving in their vehicles.

4. CONCLUDING REMARKS

The following concluding remarks can be drawn from the present study.

1) For the design of main structural components of composite steel-concrete girder fly-over bridge, namely longitudinal girder, crossgirder and column, the current design practice gives conservative results in comparison with the measured values.
2) For the renovated Thai-Belgian fly-over bridge, the stresses of longitudinal girder, cross girder and column from the test are lower than the allowable values from AASHTO specification. Hence, the main structural components of the bridge are safe to carry the design Thai truck of 31.4 tons in the static case.
3) From the dynamic test, the measured peak acceleration is less than the acceptable value, which is concerned with the perceptibility of the driver. Besides, the measured peak velocity is also categorized in the slight walking difficulty in case of pedestrian bridge. Hence, the serviceability of the Thai-Belgian bridge is guaranteed.

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Table 6 Measured peak acceleration and peak velocity

Truck speed (km/hr)	Acceleration (m/s^2)	Velocity (m/s)
5	0.310720	0.013660
10	0.517170	0.021997
15	0.255699	0.011787
20	0.683247	0.027645
30	0.405924	0.019613
40	0.629024	0.037986

Table 7 Serviceability limit of pedestrian bridges [5]

No.	Content of category	Lower limit peak value (m/s)
1	Lightly perceptible	0.006
2	Definitely perceptible	0.012
3	Slight walking difficulty	0.024
4	Great walking difficulty	0.038