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FULL SCALE LOAD TESTING TO FAILURE
OF A.R.C RIGID FRAME TYPE BRIDGE

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ABSTRACT

Bridge agencies around the world are today paying much attention to the evaluation of bridge performance. Public Works Department Malaysia (PWD), as the agency responsible for some 5000 bridges in the country has often been required to assess the structural load capacity of existing bridges. The conventional method used involved back calculations using some simplifications. There are some inherent problems with this conventional approach. As such, the calculated load capacity has always been very much lower than the 'actual' load capacity (as was evident in some testings carried out in Canada). A severely deteriorated single span R.C. frame bridge structure was to be demolished to make way for a new bridge. The PWD availed itself of this opportunity to test load the bridge to collapse in an attempt to determine the mechanism of failure and the ultimate load capacity of the bridge. Also of interest is the lateral load distribution and load redistribution characteristics of the structure near failure. This paper describes the procedures of testing and the instrumentations used in the test. Conclusions derived from observations made during the test as well as from the analysis of test results are presented. These include the lateral load distribution both at elastic and inelastic states. The entire test process was recorded in a video tape.

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1.0 INTRODUCTION

The Public Works Department Malaysia (PWD) is responsible for the management of some 5000 bridges in Malaysia. As a bridge agency in this country, the PWD is often required to assess the structural integrity of existing bridges to ensure public safety; and to evaluate the effect of abnormal vehicles against the load-carrying capacities of the bridges to be crossed.

In either case, a structural analysis of existing structures in question has to be made. Traditionally, a detailed inspection is made in which measurement of the bridge dimensions is taken. As-built drawings will be referred to, if they are available. Back calculation is then made that invariably require some assumptions and simplifications. Finally, based on the conditions of the structure the calculated load capacity is appropriately discounted.

There are inherent problems with this conventional approach:

i. Simplified lateral distribution of wheel loads;
ii. Assumption made of the mode of failure;
iii. Procedures based on results from tests performed in the laboratory or field load testing within elastic range only;
iv. Failure to consider the entire structural system.
v. Ignoring the stiffening effects of parapets or the presence of composite actions.

As a result, the calculated load capacity is often very much lower than the 'actual' load capacity, as was evident in some testings carried out in Canada (Bakht & Jaeger 1988).

Indeed, the conventional analysis sceptically called the 'cookbook' method is now under fire and experts are looking for a more reliable method to assess the performance of an existing bridge (1990). Apparently, full-scale load testing is the only reliable method available now to evaluate the structural integrity of a bridge.

In Malaysia, a severely deteriorated single span R.C. frame structure was to be demolished to make way for a new bridge. The PWD availed itself of the opportunity to test load the bridge to collapse in an attempt to determine the mechanism of failure and to determine the ultimate capacity of the bridge. Also of interest is the lateral load distribution and load redistribution characteristics of the structure near failure.

The full-scale load test on bridge 375/5 was conducted by the main contractor responsible for the reconstruction work through its sub-contractor. The work was in fact included in the contract as an addition variation order because the need to test load the bridge came as an afterthought.

This paper describes the procedures of testing and the instrumentations used in the test. Conclusions derived from observations made during the test as well as from the analysis of test results are presented. These include the lateral load distribution both at elastic and inelastic states.

2.0 BRIDGE DESCRIPTION

Bridge 375/50 is located in the Kuala Langat District, Selangor and is approximately 375.5 km away from Johor Bharu along Federal Trunk Route No. 5. It is an R.C. rigid frame-typed structure with 4 R.C. beams monolithically cast with the R.C. slab. The beams are laterally stiffened by 5 R.C. diaphragm beams. The columns of the portal frames are extension of the 300 mm x 300 mm R.C. piles. At the abutments, R.C. retaining walls were cast behind the piles and bear on them.

A detailed condition survey was done jointly by the contractor and the PWD staff a few weeks before the testing. In the survey, detailed dimensions of the bridge and concrete cover to reinforcement were measured and recorded. This data was later used for back calculation to determine the theoretical performance of the bridge. The bridge has a width of 5.8m and a length of 6.3m. It is interesting to note that the thickness of the bituminous surfacing was found to be 290 mm thick due to many years' overlaying work. Figure 1 is a sketch showing the elevation of the bridge.

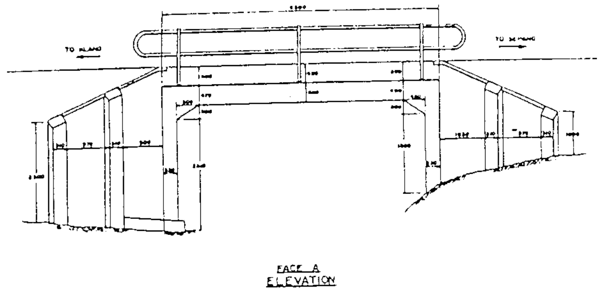


Figure 1: Elevation view of the bridge as viewed towards downstream.

Figure 2. Note the severe Corrosion of Reinforcement.

The detailed inspection also revealed that the bridge was badly damaged, especially at the pile up-stands (figure 2). The superstructure was in rather good condition except for the two edge beams which showed signs of localised corrosion at the mid-span. Carbonation tests carried out by the contractor indicated that carbonation was severe with some spots as deep as 49 mm from the surface while in most other parts, the affected depth was 10 mm. Concrete core tests done on the slabs, beams, columns (piles) and abutment walls gave an average cube strength of 29.0 N/mm2, 25.0 N/mm2, 47 N/mm2 and 27 N/mm2 respectively. Static Modulus of Elasticity for beam was 14,100 N/mm2 while the value for column was 28,700 N/mm2.

3.0 TESTING PROCEDURES

3.1 OBJECTIVES OF TEST

The purpose of the load test was to gather relevant data to achieve the following objectives:

i. To determine the amount of lateral load distribution for the bridge system tested; particularly near the ultimate limit.

ii. to determine the modes of failures pertinent to the bridge type.

iii. to determine the ultimate load capacity of the bridge.

iv. to determine the redistribution property of the bridge as the structural system fails.

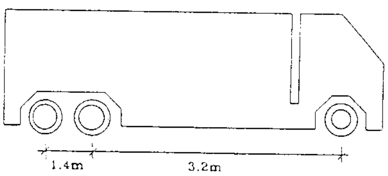
As this was the first and only full-scale load testing ever conducted in Malaysia, the test would also serve as a reference and guide for future testing(s).

3.2 TEST PROCEDURES

The test consisted of two stages:

Stage 1: Truck Load (of fixed magnitude) at different load positions;
Stage 2: Stationary Dead Load (with load increment until failure)

Stage 1 Loading was designed to obtain the lateral load distribution characteristics of the structure within the elastic limit. Two trucks overly loaded with aggregates were used. Each truck had a front axle and two rear axles, 1.4 m apart, the dimensions of which are given in figure 3. The weight of each axle was weighed using a portable weigh bridge and the twin axles were found to be of equal load. The loads provided by the trucks were of fixed magnitudes but the loading positions were varied to include all possibilities of causing the maximum load effects.



Lorry Reg. No.	Weight of Front axle	Weight of Rear axle 1	Weight of Rear axle 2
WCL 5361	5.56	15.76	15.57
WCL 5712	5.69	16.97	16.42

All weight in Ton

Figure 3: Axle configuration and weight.

Stage 2 Loading was designed to cause complete failure of the bridge. It is essential that the term 'failure' be defined here. As was mentioned earlier in the preceding section, the purpose of the full scale load test was to investigate the performance behaviour (load paths) of the bridge system as the weaker members fail leading eventually to the failure of the whole structural system. In this regard, failure was defined as the complete collapse of the entire structure. A catastrophic collapse of the bridge was expected.

Concrete blocks each weighing between 3.5 to 4.8 tons were used to provide the stationary dead load. The exact weight of the test blocks were weighed with a load cell connected to the lifting hook. The accuracy of the load cell was 0.01 kN.

3.2.1 Preparation for Testing

A few weeks before the load test, the bridge was closed to the public and the traffic diverted to a temporary bridge. The surfaces of the beams were white-washed with slaked lime. This was for the purpose of detecting any cracks and also capturing the stress patterns of failure. The loading positions were clearly and permanently marked with white paint on the deck surfacing. The integrity of the linear displacement transducers and strain gauges installed was checked and monitored over a period of more than 24 hours to ensure proper functioning during the load test since the water level was subject to tidal fluctuation; and the gauges might be submerged under water.

3.2.2 Instrumentation

A total of 36 resistance-wire strain gauges were used in the test. The gauges were manufactured by TML of Japan with an accuracy of 1 micro strain. Polyester gauges with a gauge length of 120 mm were used for concrete measurement while foil gauges of 3 mm gauge length were used for steel measurement. Gauges were installed in positions to record and monitor the load effects in terms of longitudinal strains (see figures 4a & b).

Linear displacement transducers were installed at mid-spans and quarter spans of the beams to measure and monitor the deflection of the beams due to each load case. A high sensitivity stepless spring loading LDT with a range of 100 mm reads to 0.01 mm was used. Precise level measurements were also carried out to monitor any settlement at the abutments and to check the steel frame supports for the linear displacement transducers. This was done by installing precise level station at specific locations at the abutment walls/piles and steel frame support.

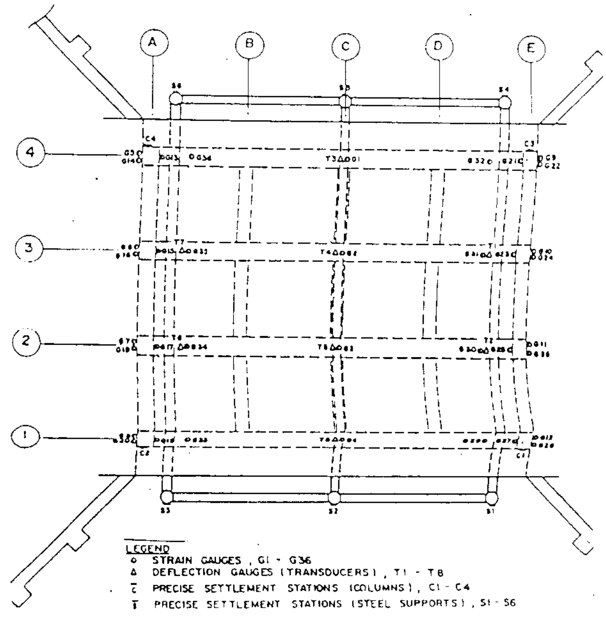


Figure 4a: Plan Location of instruments

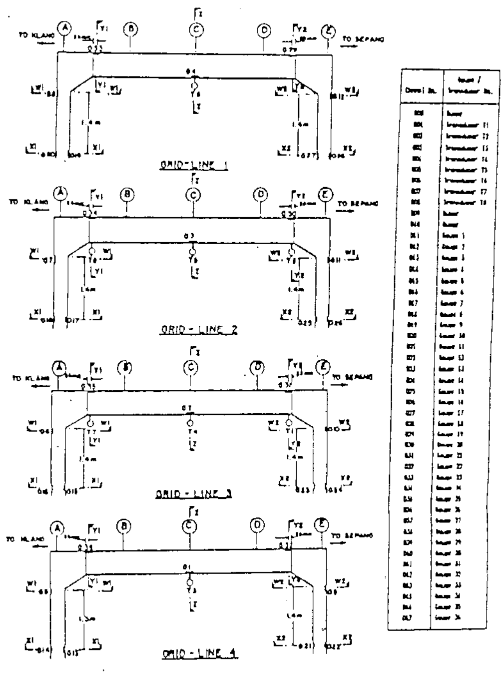


Figure 4b: Location of instruments

The readout unit for strain measurements was an automatic data logger with automatic printout. The data logger together with the switch box can read up to 500 channels at a scanning speed of 0.08 channel per second. The data logger was linked to a portable computer with software to enable measurements and plotting (load-deflection and load-strain curves) be instantaneously displayed on the computer screen.

3.2.3 Loading cases

For each stage of testing there were a number of different load cases. For stage 1, there were 16 load cases involving two loaded trucks in various positions. For each of these load cases, the readings of the gauges and transducers were automatically logged. For the purpose of this paper, only the effects due to load sequence LS2, LS3, LS5, LS12, LS13 and LS15 are reported in section 5.0. Figures 5a, 5b and 5c, show sequences LS2, LS3 and LS5. Loads LS12 and LS13 are mirror images at the centre span of the bridge, of load LS2 and LS3 respectively. Load LS15, is on the other side of the bridge to load LS5 and the truck is facing the opposite way.

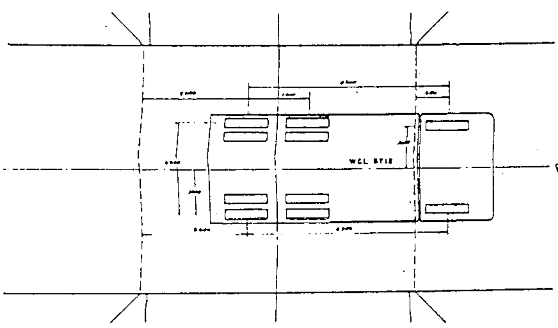


Figure 5a: Axle Load sequence No.2 (LS2)

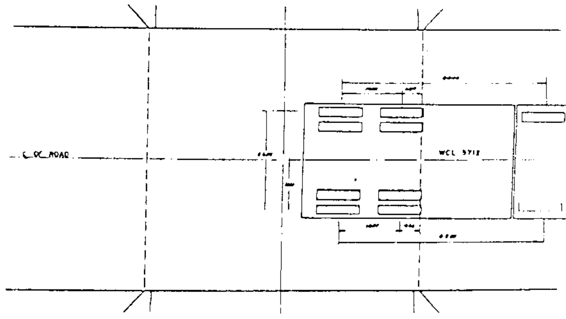


Figure 5b: Axle Load sequence No.3 (LS3)

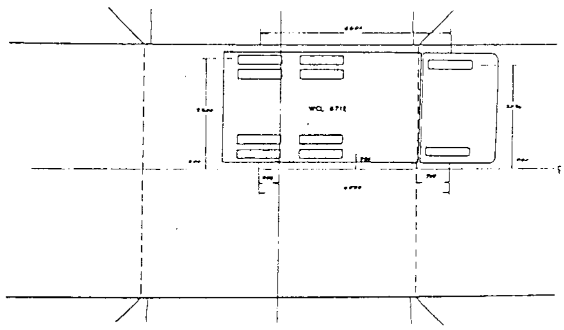


Figure 5c: Axle Load sequence No.5 (LS5)

For stage 2 testing, it was originally proposed that two concentrated loads of 1.8 m apart be applied against a kentledge of concrete blocks to simulate the PWD standard wheel loads (1990). There was however a difficulty in the design of the testing rig which had to span across the length of the bridge. It was therefore decided that concrete blocks be used as dead load instead. The loading was applied over an area of 6.3 x 5.8 m (see figure 6) using two 30-ton cranes. One crane was used for the placement of the concrete blocks while the other was used to hoist up a worker to help position the concrete block in place. The precaution taken had proved to be necessary when at one stage of the loading the loading block fell down. The strains and deflections were recorded for every 20 tons load interval.

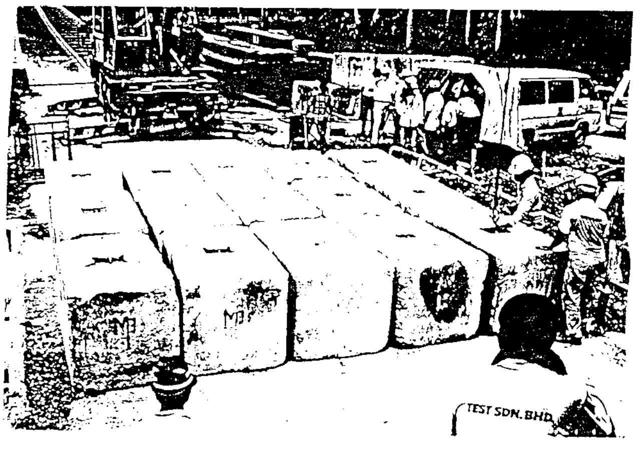


Figure 6: Scene of load test at 51.4 Tons

4. TEST RESULTS

The results of the load test was reported in figures 7 to 10. Negative values indicate compression strain and positive values indicate tension strain.

Hairline cracks were observed on Beam No. 4 at a total load of 190.16 tons. At about 295 tons, the structure began to show signs of failure, at 309 tons the superstructure showing plastic state behaviour. The structure would collapse if the load was maintained. Lest there was any accident due to unexpected catastrophic failure, an additional piece of concrete block was placed to initiate failure (figure 11). Then the 'Kuala Langat bridge is falling down (see figure 12).

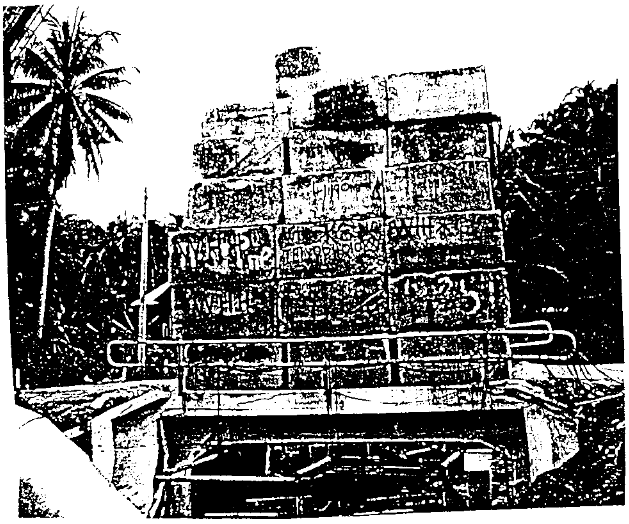


Figure 11: At maximum load 320.67 tons. The bridge collapsed about 3 minutes after the final load was applied.

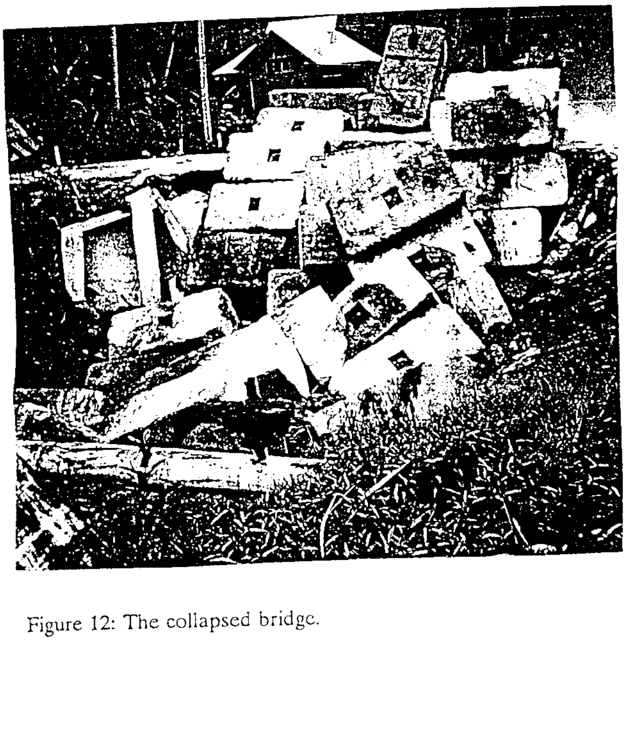


Figure 12: The collapsed bridge.

5. INTERPRETATION OF RESULTS

5.1 Stage 1 loading

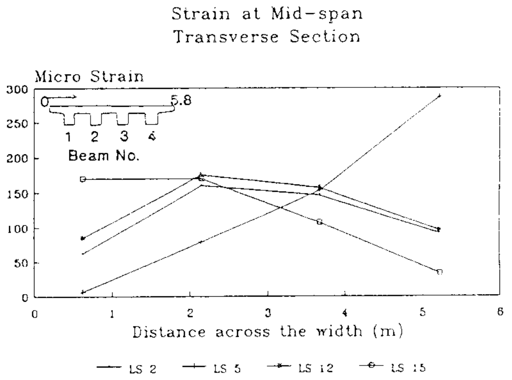


Figure 7: Strain at mid-span from axle loadings.

The figure above showed the lateral load distribution of the superstructure at the elastic stage. For loads at the middle of the bridge, the two interior beams have higher strain. Similarly, when the load is on side of the bridge, the respective edge beam strained more than the other three beams.

5.2 Stage 1 loading

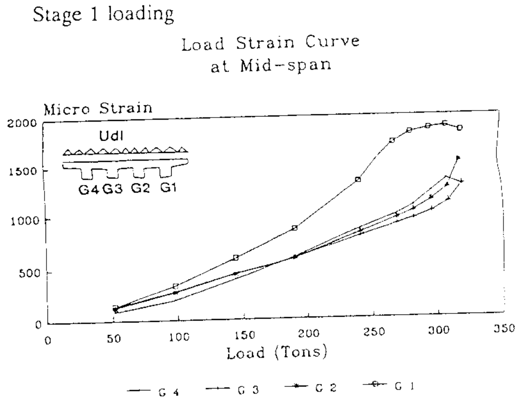


Figure 8: Strain curve at mid-span, for beam 1 to 4.

This is a stress strain curve. It can be seen that the pair of interior and edge beams showed similar trends. At non linear phase, there appear to be convergence of strain of the interior and that of its immediate edge beam.

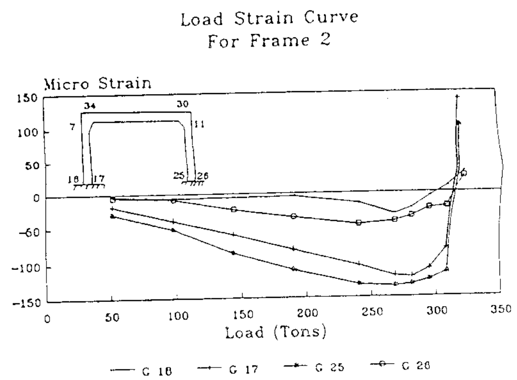


Figure 9a Strain curve for gauges 17, 18, 25 and 26.

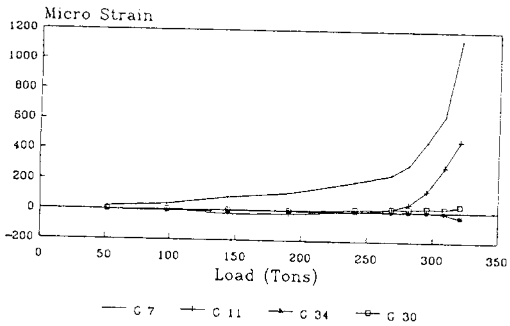


Figure 9b: Strain curve for gauges 7, 11, 34 and 30.

These two figures showed that, the wall at G7, G11, G17, G18, G25 and G26 entered the non linear load and strain relationship at 268 tons. The strain readings before failure, for G7 and G11 indicated that they are in tension and the bottom walls are in compression.

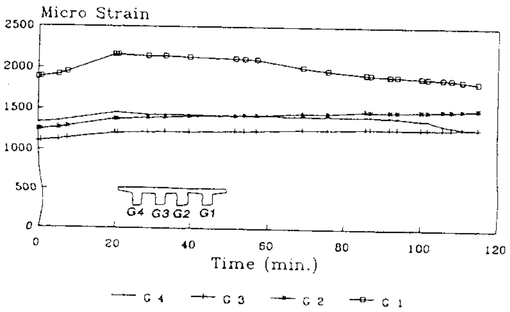


Figure 10: Constat load strain curve at mid-span, for beam 1 to 4.

At constant load of 309 tons, the beams are well into the non linear range. As was demonstrated by the curves in figure 8, the edge and its intermediate interior beam approached or are converging to the same strain. This can be clearly seen in the figure above, for gauges G3 and G4.

6. DISCUSSION AND CONCLUSIONS

6.1 Stage 1 loading

Under this loading conditions, when the truck was at the centre line of the bridge, the load distribution factor are found to be 0.39, 1.00, 0.91 and 0.57 for beam 1, 2, 3 and 4 respectively. Similarly, under one lane loading the load distribution factors are 1.00, 1.00, 0.63 and 0.2 for the same beam configurations. These are demonstrated by the load strain curve of figure 7, for loads LS2, LS5, LS12 and LS15.

6.2 Stage 2 loading

Under UDL load, the behaviour during the initial stage is similar to the to the truck loads as the structure is still in the elastic stage. Beam G1 is seen to be weaker than the other three beams, however after 282 tons, as the structure enters the non linear phase, the super structure began to demonstrate the load distribution patterns. As shown by the rapid increase in the strain of the other three beams as was shown by figure 8. The curve in figure 10 also showed that, the strain in the weaker beams are reducing and that of the stronger beams are increasing, which indicate that load redistribution occurred.

It is also noted that, in figure 9a and b, the non linear phase occurred at loading of around 268 tons, earlier than that of the beams. This showed that the decks are very much stronger than the wall/column.

6.2.1 Collapse

The actual collapse of the structure occurs at a load of about 320 tons, with the whole superstructure falling into the river virtually in one piece. It is obvious that the pile bent system at the embankment is the weakest in the overall structural system. The piles buckle first even though the super structure also begins to show sign of yielding.

7. CONCLUSION

The structure behaves linearly until a load of about 282 tons. Beyond 300 tons, buckling of pile column becomes evident, as seen from the sudden collapse of the complete superstructure, although the mid-span of the superstructure is also showing sign of yielding. Redistribution of loads for such a structure is not very efficient possibly due to the diapghram beams themselves are not sufficiently stiff. Some distribution is seen only towards or near collapse state.

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