

REPORT
THIRD PARTY AUDITING OF RAILWAY BRIDGES (PHASE I)

(Job No: CED/CON/TMMP/SAS/2019312)

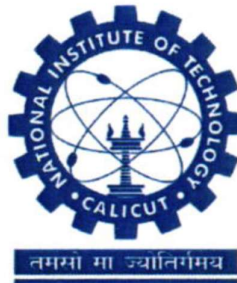
**Br. No. 136 (1×6.1 m) Stone arch bridge at km. 45/700-800 between
Melattur & Tuvvur Stations**

CLIENT



SOUTHERN RAILWAY PALGHAT DIVISION

CONSULTANT



Department of Civil Engineering
NATIONAL INSTITUTE OF TECHNOLOGY CALICUT

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1. PREAMBLE

Director, NIT Calicut received a request from Chief Bridge Engineer, Headquarters office, Chennai Works Branch, Southern Railway vide letter No. W.439/4/61/Vol.IV(W.245/I/1 Spl. Drive) dated 18 – 09 - 2018, exploring the possibility of whether NIT Calicut can undertake a one - time third party auditing of some selected railway bridges. This was consequent to the instruction issued by Railway Board to various railway divisions for undertaking such inspections of railway bridges through expert institutions. The letter was forwarded to the Civil Engineering Department (CED) and the Structural Consultancy Group of CED followed the matter up. The Railway Board was represented by Palakkad division of Indian Railway. Subsequently, on 05 – 10 - 2018 railway officials came to CED, NITC for discussions. Soft copies of the available drawings of some of the bridges were also shared by Railways to CED for initial assessments. Subsequently, CED expressed its willingness to take up the work and communicated the matter by letter, No. CED/CON/RLY/TPAUD/2018/1 dated 08-11- 2018. Through this letter it was conveyed to Railways that the work could be taken up in two phases, outlining the scope of work to be carried out in the different phases. This was accepted by Railways and they requested the details of consultancy charges for carrying out phase I of the work.

CED replied vide letter No. CED/CON/RLY/TPAUD/2019/1 dated 10 - 01- 2019, the requisite details regarding consultancy charges and scope of the work. Railways replied to this letter showing their interest to award the work to NITC and sought the signing of an MoU to proceed further. Mutual discussions followed and an MoU was signed in the FN of 19-09-2019.

The details of communications are given below:

- i. W.439/4/61/Vol.IV(W.245/I/1 Spl. Drive) dated 18-09-2018.
- ii. Meeting held on 28-09-2018 at NIT Calicut with railway officials.
- iii. J/W/71/G dated 23-10-2018 from Divisional Office, Palakkad division furnishing details of some of the bridges.
- iv. CED/CON/RLY/TPAUD/2019/1, dated 10th January 2019
- v. MoU between Southern Railway and NIT Calicut, dated 19-09-2019.
- vi. CED/CON/HOD/TMMP/SAS/2019312, dated 3rd October 2019
- vii. J/W.71/G, dated 03-12-2019
- viii. CED/CON/HOD/TMMP/SAS/2019312/1, dated 02-01-2020
- ix. CED/CON/HOD/TMMP/SAS/2019312/2, dated 02-01-2020
- x. CED/CON/HOD/TMMP/SAS/2019312/3 dated 23-01-2020

- xi. CED/CON/HOD/TMMP/SAS/2019312/4 dated 11-03-2020
- xii. CED/CON/HOD/TMMP/SAS/2019312/5 dated 12-03-2020
- xiii. CED/CON/HOD/TMMP/SAS/2019312/6 dated 13-03-2020
- xiv. CED/CON/HOD/TMMP/SAS/2019312/7 dated 11-05-2020
- xv. No. J/W.71/G dated 27-07-2020
- xvi. CED/CON/HOD/TMMP/SAS/2019312/8 dated 22-07-2020
- xvii. CED/CON/HOD/TMMP/SAS/2019312/9 dated 22-07-2020
- xviii. CED/CON/HOD/TMMP/SAS/2019312/10 dated 14-08-2020

2. SCOPE AND METHODOLOGY

Railway over bridges, which are known for their permanent resistance to vehicle loads, are exposed to large stress ranges and severe environmental conditions that may lead to damage and failure of the system. Keeping in mind the large risk and economic ramifications, it is necessary to assess the health of these structures systematically by considering all loading types namely, gravity loading and vehicle loading.

In view of the above and based on the terms and conditions laid down in the MoU, the scopes of the present investigation are identified as below.

- i. Inspection of the main structure of the bridge.
- ii. Visual assessment of cracks and deformations in the bridge
- iii. Collection of necessary data for structural modelling and analysis.
- iv. Preliminary analysis of the bridges to check the adequacy of the bridge to carry vehicular load recommended by IRC-6.
- v. Overall assessment of the bridge and its integrity.

Earthquake analysis is not carried out, since the Arch bridge code^[3] (Cl.14.1) doesn't recommend earthquake analysis for the arch bridge with spans lesser than 10m.

Considering the above aspects, the following methodology is finalised.

- i. Visual inspection of the bridge
- ii. Field measurements for modelling purpose
- iii. Condition assessment of various elements of the bridge and to summarize the results in a tabular form
- iv. Structural modelling and analysis of the bridge for stipulated loads
- v. Assessment of the strength and safety based on the analysis results

3. INSPECTION OF BRIDGE

3.1 Visual Examination

The visual inspections along with field measurements were carried out on the bridge on 17-02-2020 (Monday) at 11.00 am. Officials from Palakkad Railway section were also present during the inspection. Photographs of the bridge showing various elements are shown in Fig. 1, Fig.2 and Fig.3. The bridge is a Random Rubble (RR) masonry arch bridge with a span of 6.1 m.

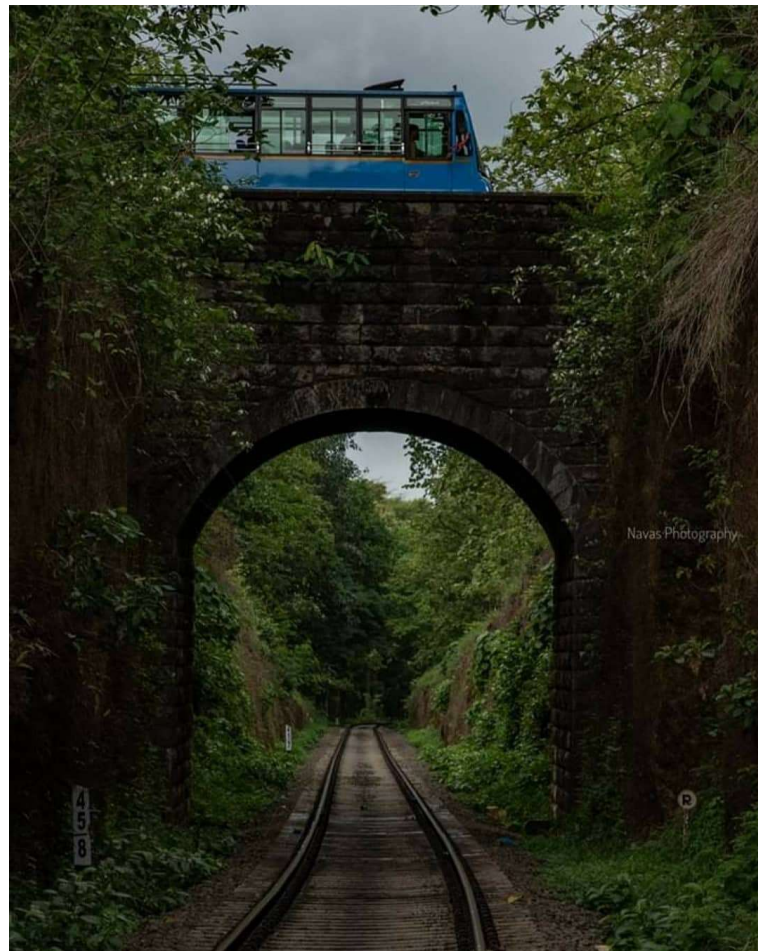


Figure 1. View of Br.136 Masonry arch bridge



Figure 2. bottom view of the bridge



Figure 3. Abutment of the bridge

3.2 Field measurements and condition assessment

The geometry of the bridge is obtained by taking measurements in the field. Fig.4 shows the details of geometry and various elements. Based on a careful examination of the bridge, the observations are tabulated in the following Table 1. The Table shows various elements of the bridge, defect type, follow up actions required and remarks. Labels are assigned to various types of defects as given in Table 2. Vegetation growth is seen on the masonry work and in backfill as shown in Figs.5 and 6.

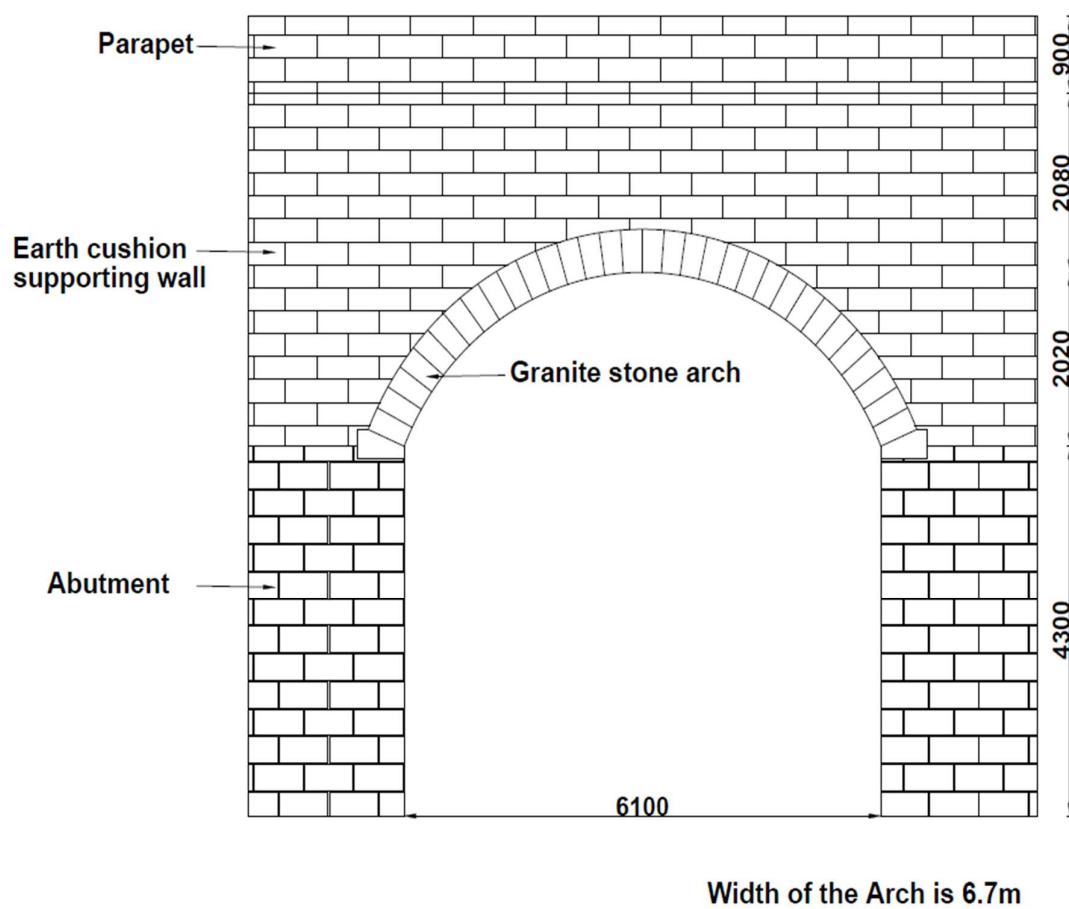


Figure 4. Geometry of the bridge

Table 1: Condition assessment of bridge

Element	Defect Type (Ref. Table 2 for details)	Follow-up actions required			Remarks
		DI	Re	De	
Abutments	07	-	-	-	
Arch stone	00	-	-	-	
Earth filling	00	-	-	-	
Parapet	07	-	-	-	
Pavement	00	-	-	-	

* Legend: DI – Detailed Investigation; Re – Repair; De – Demolition

Table 2: Different defect types and their designation

Defect Type	Label	Defect Type	Label
Cracks in stone masonry	01	Foundation settlement	05
Pavement settlement	02	Percolation of water through RR masonry	06
Signs of overloading	03	Vegetation growth	07
Distress in masonry (in mortar joints)	04	No visible defect	00



Figure 5. Vegetation growth in backfill near the bridge

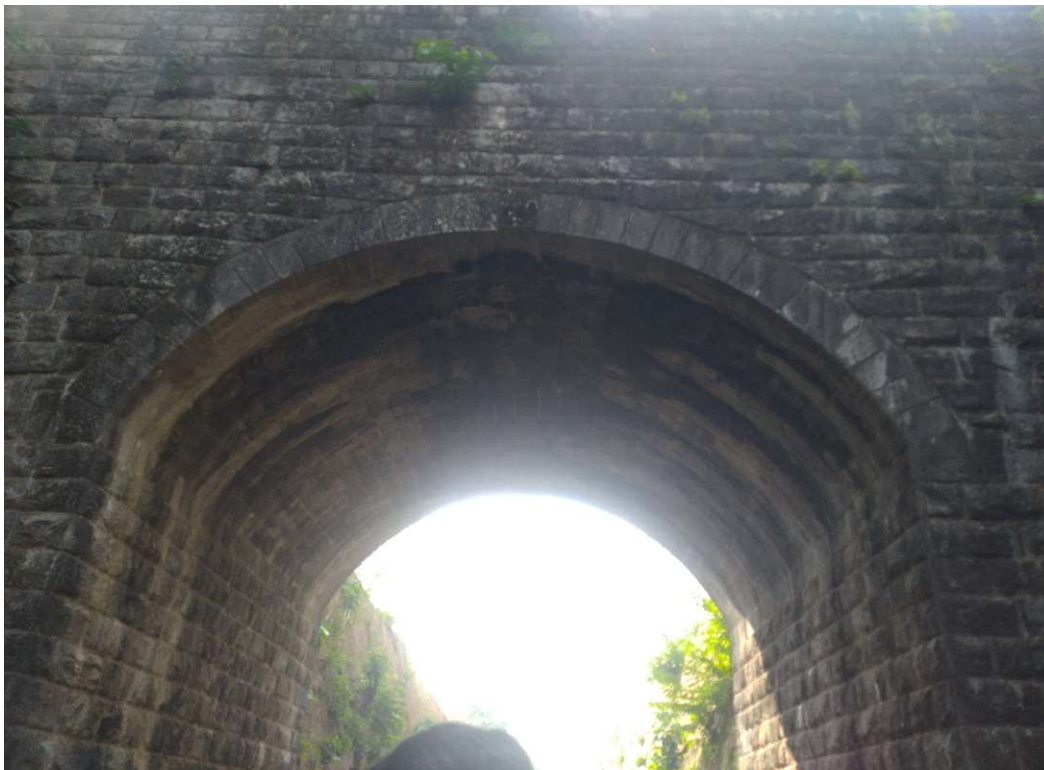


Figure 6. Vegetation growth above the crown

4. MODELING AND ANALYSIS

4.1 Description of loading and analysis

In the present work, one of the requirements is to check the adequacy of the bridge to vehicular loading. In this report, the specification of loads is based on IRC 6:2014 and IRS (*Code of practice for the design and construction of masonry and plain concrete arch bridges*). Accordingly, IRC class 70R loading (Cl. 201.1) has been used for calculations (Fig.9). Position of live load along the bridge is decided as per the Arch bridge code recommendation (Cl.5.1). Analysis was done using SAP2000 software. Computational model of the arch structure and the stress variation along the arch are shown in Fig.7 and Fig. 8 respectively.

The detailed calculation of loads and analysis is done following relevant bridge codes [1][2][3][6], which are furnished in Appendix 2 which gives the demand of the various elements of the bridge.

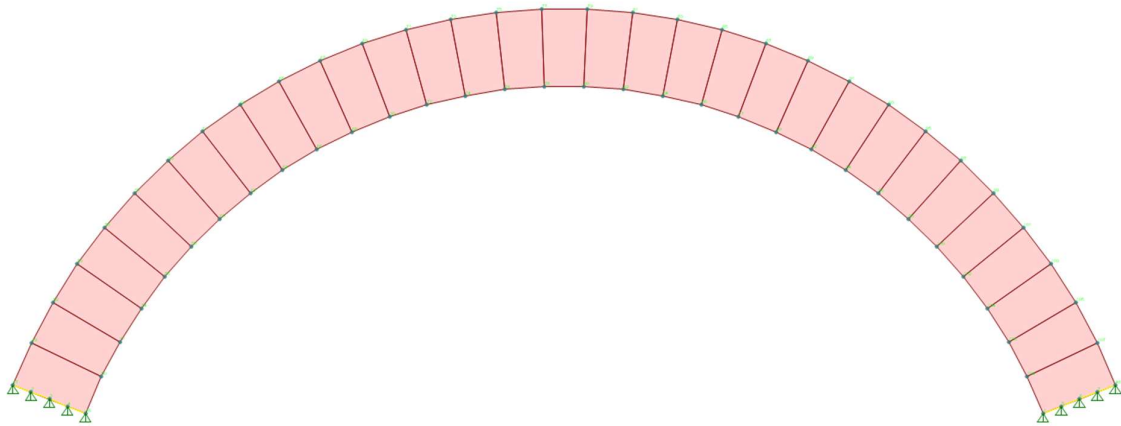


Figure 7. Arch bridge model

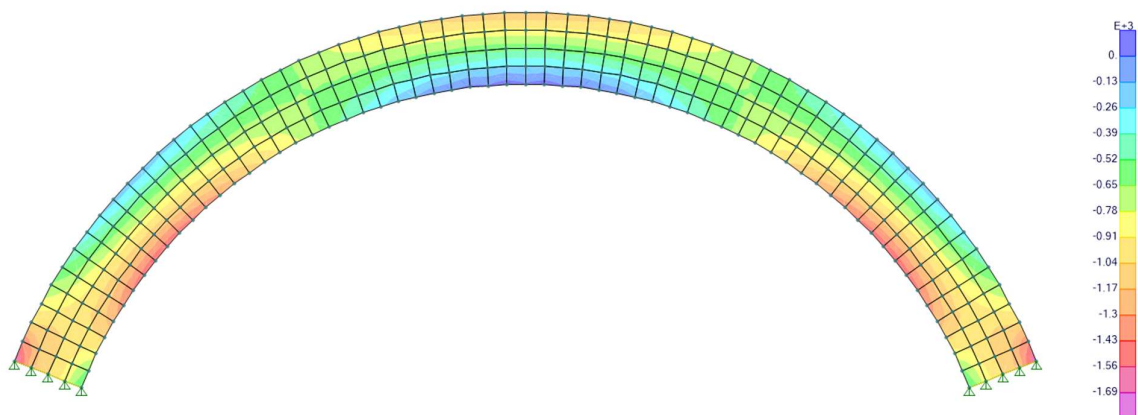


Figure 8. axial stress distribution along the span of arch

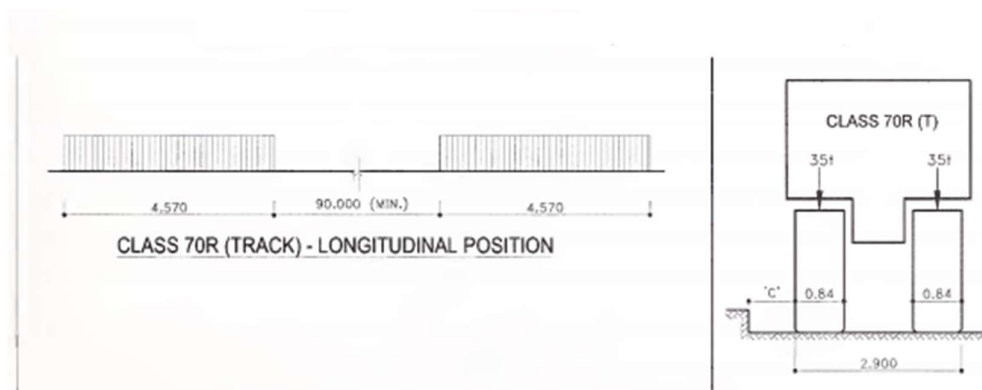


Figure 9. Wheel load arrangement for 70R loading

4.2 Safety assessment

4.2.1 Strength aspect

The integrity and safety of the bridge are assessed by the demand capacity ratio. The capacity of arch section is evaluated considering the effective section. Table 3 gives the result of the analysis.

Table 3: Analysis result

Sl No	Element/Section force	Demand (MPa)	Capacity (MPa)
1	Axial thrust on arch segment	1.72	2.5

4.2.2 *Stability aspect*

Appendix 1 portrays some of the common mode of failures of masonry arch bridges summarized based on past literature. Some of them are failures that can be attributed to stability issues. Careful examination of the various elements of the current bridge gave clear indication that there are neither such *insitu* conditions nor are there any indication of future possibilities. The backfill appears to be strong and there are no erosions seen. So it is assessed that the masonry arch bridge is sound in terms of stability too.

5. COMMENTS AND INFERENCE

Table 3 shows that arch bridge has sufficient reserved capacity against gravity loading and vehicle loading, thus it is found to be safe. The bridge is assessed to be stable also based on the visual inspection. In view of these the bridge is deemed to be **safe and stable**. It is suggested to monitor the bridge and the abutment on a regular basis and clean the unwanted vegetation growth which if neglected may lead to soil erosion and subsequent distress to the bridge.

Members of the Investigation team

1. Dr. T.M. Madhavan Pillai (Coordinator)
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4. Dr. Robin Davis P.
5. Dr. Sajith A.S.

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REFERENCES

1. Bridge Rules, 1964. Rules Specifying the Loads for the Design of Super-Structure and Sub-Structure of Bridges and for Assessment of the Strength of Existing Bridges.
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2. Standard, I.R., 2013. Code of practice for the design of sub-structures and foundation of bridges. *Research Designs and Standards Organisation, Lucknow.*
3. IRS Arch bridge code: Code of practice for the design and construction of masonry and plain concrete arch bridges.
4. IRC 40:2002 – Standard specifications and code of practice road bridges.
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7. Conde, Borja, Luís F. Ramos, Daniel V. Oliveira, Belén Riveiro, and Mercedes Solla. "Structural assessment of masonry arch bridges by combination of non-destructive testing techniques and three-dimensional numerical modelling: Application to Vilanova bridge." *Engineering Structures* 148 (2017): 621-638.

Appendix 1

Failure conditions of stone arch bridge

Stone arch bridges may fail due to different reasons. Some of the condition for failure of an arch bridge are shown in Fig.10.



Figure 10: (a) abutment (b) buttress (c) stone deterioration at the crown of arch (d) in-plane deformations of arch and stone deterioration at the crown (e) cutwater (f) out-of-plane deformations and cracks at the spandrel wall (g) damaged pathway.

Appendix 2

Arch Bridge Design check

Geometry of the arch bridge

Span =	6.1	m
Thickness=	500	mm
height of crown=	2.02	m

Loading

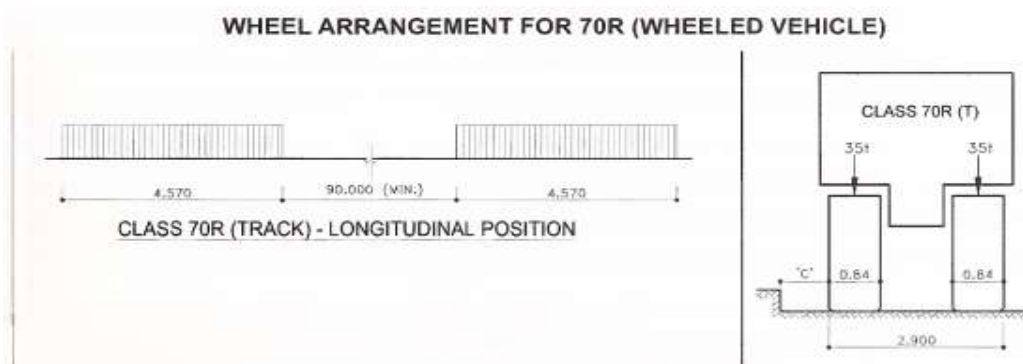
1) dead load

As per the Clause 2.1 of the Arch Bridge Code, the dead load transmitted to the arch is assumed to act vertically. The horizontal pressure acting on the arch ring may be neglected

self weight of arch =	16.45 kN/m ²	(total 31 stones for a length 6.1m)
Earth fill =	49.56 kN/m ²	(equivalent depth of 2.75m)
weight of pavement =	11 kN/m ²	

2) Live load

IRC class 70R Loading is adopted for the checking of the Bridge



The road is two way single lane road. Hence Two 70R wheeled vehicle is placed over the arch bridge conservatively.

Total vehicle load on the arch bridge =	1400	kN
Distributed load at a depth of 2.08m =	34.25	kN/m ²

Analysis

Arch bridge is analysed using SAP2000

property assigned:-

modulus elasticity of Granite = 30000 Mpa

Poisson ratio = 0.2

Shear modulus = 12500 MPa

As per the Clause 403.4.2 of IRC 40:2002 , for an arch ring in ashlar stone masonry

Permissible compressive strength = 2.5 MPa

From the analysis

Axial compressive stress in the arch ring = 1.72 MPa < 2.5 Mpa

Hence the structure is safe