ISSN: 0974-5823 Vol. 6 No. 3 October-December, 2021

International Journal of Mechanical Engineering

Analytical Study on Flexural Behaviour of Voided Concrete Beams

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***Abstract*-The voided beams are the concrete beams that are incorporated with a specified shape of void formers that can eliminate concrete in the tension zone. Hence it is used to reduce the consumption of the concrete. In this paper, voided beams are tested to study the effect of the size of the rib on its flexural behaviour. The minimum rib size of voided concrete member has to be 65mm. This paper investigates the influence of the rib size on the flexural behaviour of voided beams. A solid concrete beam and voided concrete beams with varying rib sizes are studied numerically and an experimental program is proposed. The beams are studied numerically using finite element software ANSYS. The voided beams with 65mm, 60mm and 55mm are analyzed numerically. The behaviour of voided beams is compared with that of the solid reinforced concrete beam.**

Keywords: Voided beam, solid concrete beam, void formers, reinforcement, ribs, flexure, tension zone, ANSYS.

1. Introduction

Concrete is the second most consumed material by humans, behind water. There is an increase in demand of the concrete in the world; so many alternatives for concrete are suggested now[1]. There is an increase in manufacture of cement, leads to more Carbon dioxide emissions. The usage of concrete must be optimized. One such technique is to use voided concrete members. The voided concrete members are incorporated with void formers in such positions where the use of the concrete is insignificant. Subjecting the beam to a bending moment, the compression is taken by the concrete above the neutral axis and the tension is taken by the steel reinforcement bars below the neutral axis[2][3]. The concrete present below the neutral axis is used only for the stress transfer and is considered to be insignificant. Thus, the concrete in those places are replaced with void formers leading to reduction in the usage of concrete. This leads to reduction in self-weight of the concrete members, which ultimately results in lighter structure and foundation, thereby optimizing the usage of construction materials[4][5].

According to Indian standards, the minimum rib size for a voided concrete member is 65mm. The portion of concrete present between two voids is called the rib. In this paper, the effect of rib size in the voided beam is studied both numerically and experimentally[6][13]. The size of the rib is reduced to 60mm and 55mm and the behaviour of such members are studied and compared with that of the solid reinforced concrete beams[7][12].

2. Literature Review

Awadh Ewayed Ajeel et al. tested the beams voided with 90mm spherical shaped void formers achieving about 10% reduction in self-weight. The ultimate strength of the voided beam is 13% less than the solid beam. Cracking load of the voided beam is 10% less than the solid beam under bending moment. The structural behaviours of both the beams are found to be similar[8].

Thaar et al, investigated the structural behaviour of reinforced concrete one-way slabs voided by polystyrene balls. The tests are conducted on a solid slab and a series of voided slabs voided with different diameters of balls. The failure mode of the slabs is influenced by the polystyrene balls present in the slab. The failure mode changes from flexural to shear when the balls with diameter equal to 75% of the slab depth [9].

Gee-Cheol Kim and Joo-Won Kang reviewed many papers related to voided RC members and presented some significant methods of calculating rigidities of the voided concrete members. It has been assumed that voided region is equivalent to a solid region of the same overall size but with reduced elasticity modulus[10].

Ajay Hirapara, and Dhananjay Patel (2017) analyzed voided slabs numerically by ANSYS. Material models and parameters of the concrete element and steel element are tested and listed in their study. The deflections under service load of voided specimens were found to be little higher than those of a solid slab[11].

3. Material modelling in ANSYS

3.1 Material properties

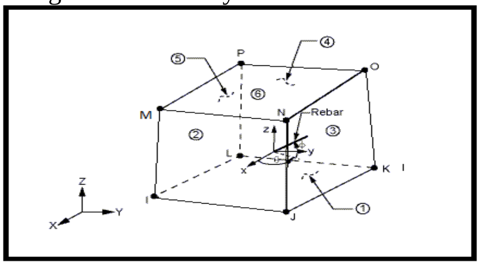
Each element has different properties of materials and the behaviour of each element is given by the nodes and their structure. For concrete, solid element type 65 can be used and for the reinforcement given in the beam, link type element 180 is used.[12]

3.1.1 Concrete

The non linear response of reinforced concrete is modelled by the solid 65 element. The solid 65 element undergoes plastic deformation and cracks in the orthogonal direction at each integration point. If the element stiffness matrices are changed and the material properties of the concrete are adjusted, the cracking of the concrete is modelled. The concrete is assumed to be cracked or crushed at an integration point if the concrete is failed in all uniaxial, biaxial and triaxial compression at that integration point. The complete deterioration of the structural integrity of the concrete is called crushing. Concrete cracks in tension and crushes in compression. The solid 65 element also behaves in a similar manner[14][15].

Up to one-third of the maximum compressive strength, the stress strain curve of the concrete is linearly elastic and beyond that softening occurs and crushes at an ultimate strain[16][17]. The curve is linearly elastic up to manikin tensile strength and then crack appears and strength decreases. In this study, concrete is assumed to be homogenous and isotropic. The grade of concrete is assumed to be M25 and the parameters are listed in the table 1.

Figure 1. Geometry of Solid 65 element.



3.1.2 Steel

LINK 180 is a three dimensional spar (pole like) element that is used to model cables, truss members and reinforcement in the concrete. The element has three degree of freedom at each node and acts as a uniaxial tension-compression element. The three degrees of freedom are the translational freedom in three orthogonal directions. The option for changing the element to only tension or only compression is also available. The element can be defined by two nodes and area of cross section and mass per unit length will be given as input to the element.

Steel is assumed to be an elastic-perfectly plastic material in both tension and compression. The grade of steel is taken as Fe415 and Poisson's ratio of 0.3 has been used. Elastic modulus for steel is taken as 200,000 MPa.

Figure 2. Geometry of LINK 180

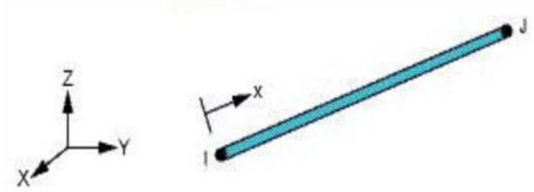


Table 1. Material properties of elements

Material	Element	Material properties	
Concrete	Solid 65	Linear Isotropic	
		Elastic modulus	27833 MPa
		Poisson's ratio	0.2
		Multilinear Isotropic	
		Strain	Stress (MPa)
		0	0
		0.00036	10.02
		0.0006	15.28
		0.0009	21.55
		0.0013	27.59
		0.0019	32.31
		0.0024	33.4
		0.003	33.4
Reinforcement	Link 180	Linear Isotropic	
		Elastic modulus	200,000 MPa
		Poisson's ratio	0.3
		Yield Stress	415 MPa

4. Modelling of test beams

Engineering problems of any type can be simulated by using Finite Element Analysis. Many analysis softwares were developed based on the Finite Element Method. ANSYS is such software used for simulation of problems related to engineering. In Civil Engineering, Structural members like slabs, beams and columns can be modelled in this software and properties of the desired material used in the members are incorporated in the software. The ANSYS software develops computer models of the structures or members and is used to study the behaviour of the modelled structure along with the properties of the material in the software itself. The ANSYS software eliminates the experimental procedures to determine the behaviour of the selected structural members. The software gives the accurate results for the analysis of the structural elements.

Four beams are modelled and analyzed in the study, a solid concrete beam, and three voided beams with varying rib size. The beams are 1800mm in length and 150mm by 200mm in cross section. All the beams are modelled with identical reinforcement pattern. The reinforcement is made of 2 numbers of 12mm diameter rod and 2 numbers of 16mm diameter rod with 8mm stirrups at 125mm centre-to-centre. The shape of void former is taken as cylinder with 30mm radius and 100mm height placed at the centre of the beam which gives a symmetrical cross-section. For the first voided beam, the rib size is provided as per Indian standards as 65 mm and for the second, the rib size is reduced to 60mm and by doing so, number of void formers is increased by 1, and for the last voided beam, the rib size is reduced to 55mm and again the number of void formers is further increased by 1. The details of the modelled beams are listed in table 2 below. The meshing of solid RC beam and voided beam are shown in Figure 3 and Figure 4.

Table 2. Details of beams

Designation	**Dimensions**	**Rib size**	**No. of Voids**
SB	150mm x 200mm x 1800mm	-	-
VB65		65mm	13
VB60		60mm	14
VB55		55mm	15

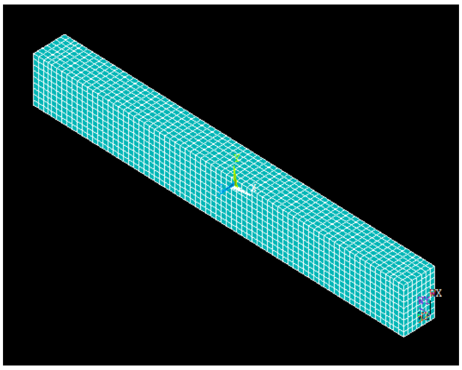


Figure 3. Meshing of solid beam

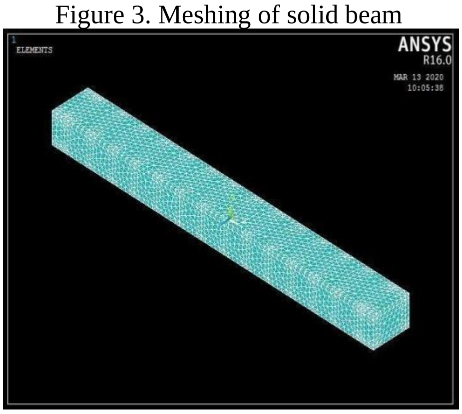


Figure 4. Meshing of voided beam

5...Loading and boundary conditions

The Flexure test or two point loading test is done on the beams to study the flexural behaviour. The beam is simply supported on two ends and two point loads are subjected on the beams at one third of the span from each end of the beam. The length of the beam between two point loads is subjected to pure flexure and failure takes place by bending. The displacement is arrested on all the three directions on one end and only on Y-direction on the other end, achieving the simply supported conditions. A load of 80kN is applied on the beam element and the analysis is carried out. The modelled voided beam is shown in figure 5.The loading and the boundary conditions of the modelled solid beam is shown in figure 6

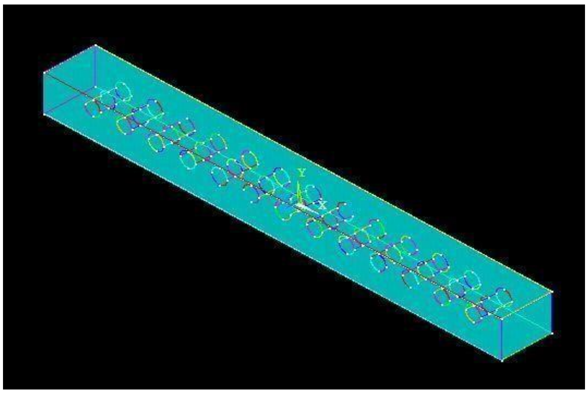


Figure 5. Modelled voided beam

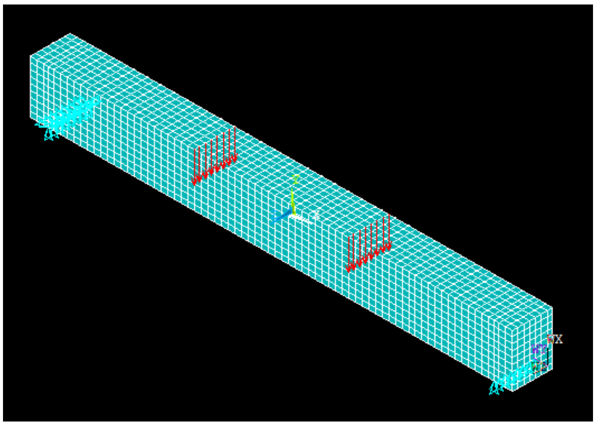


Figure 6. Loading and Boundary conditions of Solid beam

6. Results and Analysis

The modelled beams are meshed and loading and support conditions are given. The modelled beams are run by the ANSYS software. T results are obtained from the analysis run from the software. The displacements and stress distributions of the beams are shown in the figure 7 to figure14 below.

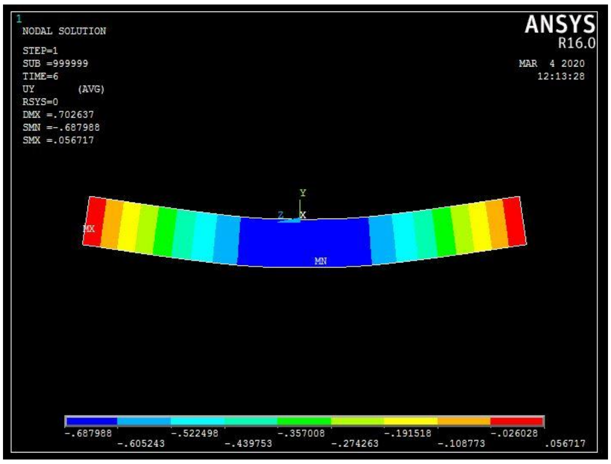


Figure 7. Displacement of SB

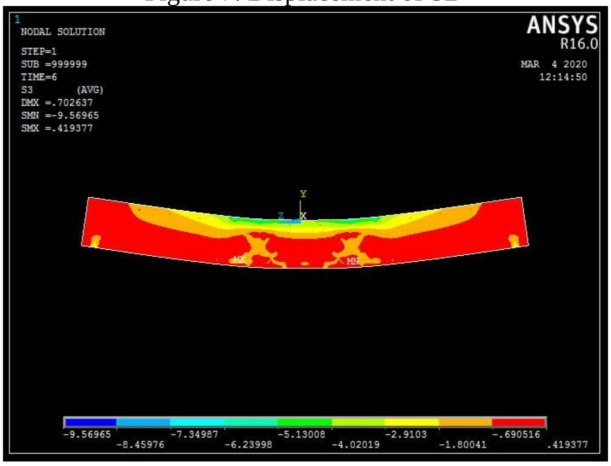


Figure 8. Stress distribution of SB

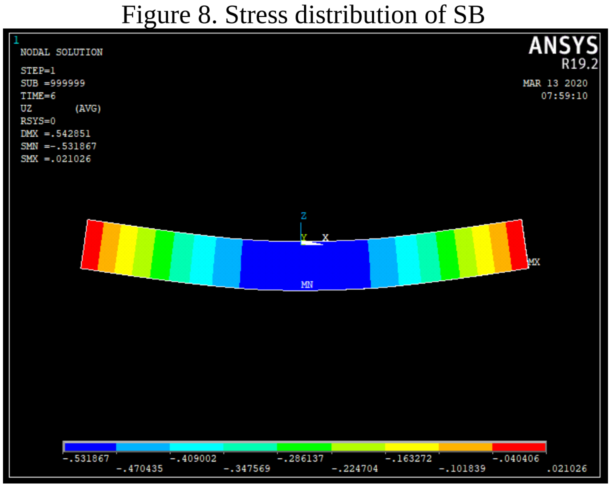


Figure 9. Displacement of VB65

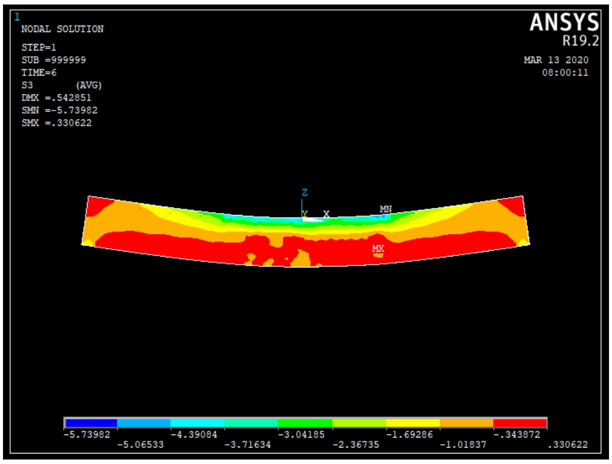


Figure 10. Stress distribution of VB65

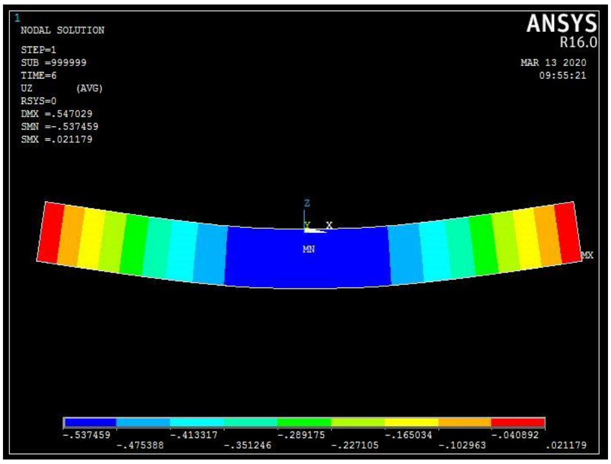


Figure 11. Displacement of VB60

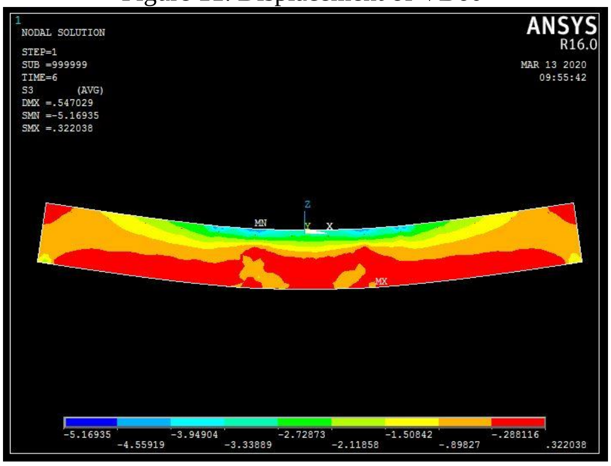


Figure 12. Stress distribution of VB60

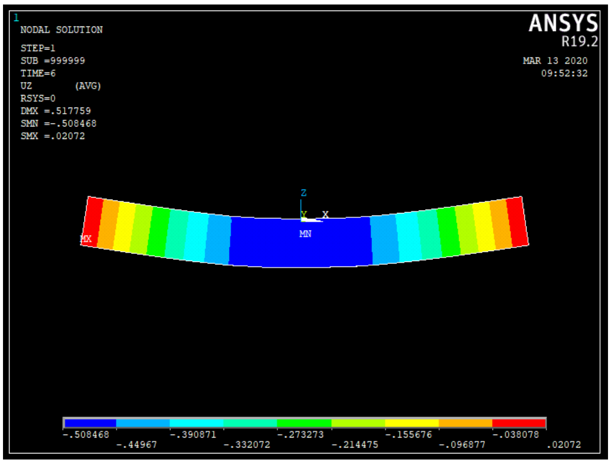


Figure 13. Displacement of VB55

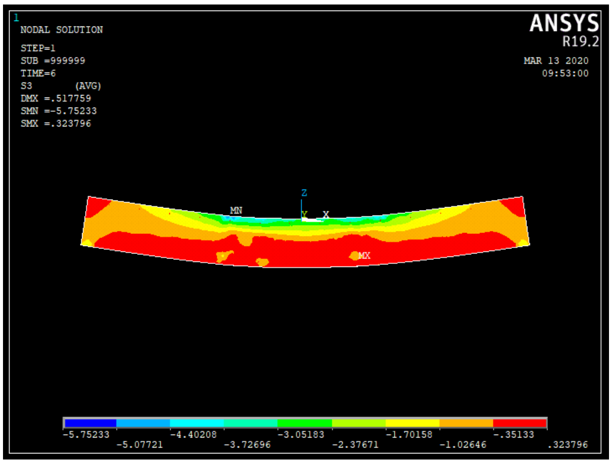


Figure 14. Stress distribution of VB55

7. Conclusions

The beams are modelled and analyzed in the ANSYS software and the results are arrived. From the results of the software, the following conclusions were made.

- The displacement of the VB65 is marginally higher than the specimen SB in the elastic region of loading. This is due to reduction in moment of inertia of the section due to the presence of voids.
- The displacements of VB60 and VB55 are greater than VB65 beam. The presence of more voids in the specimens VB60 and VB55 may be the reason for higher displacement.
- The displacement of VB55 is greater than VB65 but it is smaller than VB60 beam. The displacement is reduced by reducing the rib size from 60mm to 55mm. The arrangement of voids is similar in VB65 and VB55 and different from VB60.
- Stress distribution of the beams VB65 and VB55 are similar to each other but differ with VB60 beam.
- Behaviour of the VB65 beam and the VB55 beam are similar. It is also to be compared with the solid reinforced concrete beam to study the effect of size of the rib on the flexural behaviour. A lot of savings in concrete can be ensured in major projects like bridges, multi storey structures, pre-fabrication units etc. The self weight of the structures can be reduced by up to 35 percent and leads to an economical project scheme.

References

[1] IS: 1893(Part 1): 2016 “Criteria for Earthquake Resistant Design of Structures”, Part-1 General Provisions and Buildings, Fifth Revision, Bureau of Indian Standard, New Delhi, India.

[2] SAP 2000 Manual (Version 14), “CSI Getting Started with SAP2000”, Computers And Structures, Inc. Berkeley, USA.

[3] JAGADALE S.H. AND SHELKE N.L.,2016, “Analysis of Various Thicknesses Of Shear Wall With Opening And Without Opening and Their Percentage Reinforcement”, International Journal of Research in Engineering, Science and Technologies, Vol. 1, pp. 212- 218.

[4] BAGHERI B. et al., 2012, “Comparative Study of The Static and Dynamic Analysis of Multi-Storey Irregular Building”, International Scholarly and Scientific Research & Innovation, World Academy of Science, Engineering and Technology Vol:6.

[5] LAVANYA PRABHA, S., GOPALAKRISHNAN, M., NEELAMEGAM, M.: Development of high-strength nano-cementitious composites using copper slag, ACI Materials Journal, 2020, 117(4), pp. 37–46.

[6] MOHAN, A , VIJAYAN, D.S. , REVATHY, J., PARTHIBAN, D., VARATHARAJAN, R.: Evaluation of the impact of thermal performance on various building bricks and blocks: A review, Environmental Technology and Innovation, 2021, 23, 101577(2021)

[7] M. THOLKAPIYAN, A.MOHAN, VIJAYAN.D.S: A survey of recent studies on chlorophyll variation in Indian coastal waters, IOP Conf. Series: Materials Science and Engineering 993 (2020) 012041, 1-6.

[8] AJAY HIRAPARA, DHANANJAY PATEL, 2017, “Analysis Of Light Weight Formers In Concrete Slabs Using Voids” International Journal of Advance Engineering and Research Development (IJAERD) Volume 4, Issue 4.

[9] AWADH EWAYED AJEEL, TAMARA ADNAN QASEEM, SALWA RAHMAN RASHEED,2018, “Structural behavior of voided reinforced concrete beams under combined moments” Civil and Environmental Research Vol.10,No:1.

[10] GEE-CHEOL KIM, JOO-WON KANG, 2012, “Calculation of Voided Slabs Rigidities” International Journal of Civil and Environmental Engineering Vol:6, No:5.

[11] JOO-HONG CHUNG, HYUNG-SUK JUNG, BAEK-IL BAE, CHANG-SIK CHOI AND HYUN-KI CHOI, 2018, “Two-Way Flexural Behavior of Donut-Type Voided Slabs” International Journal of Concrete Structures and Materials.

[12] THAAR S. AL-GASHAM, ALI N. HILO, MANAL A. ALAWSI 2019,“Structural behavior of reinforced concrete one-way slabs voided by polystyrene balls” Case Studies in Construction Materials, Vol 11.

[13] GOPALAKRISHNAN, R., MOHAN, A., SANKAR, L. P., & VIJAYAN, D. S. (2020). Characterisation On Toughness Property Of Self-Compacting Fibre Reinforced Concrete. In Journal of Environmental Protection and Ecology (Vol. 21, Issue 6, pp. 2153–2163).

[14] LAVANYA PRABHA, S., DATTATREYA, J.K., NEELAMEGAM, M., SESHAGIRI RAO, M.V.,

Investigation of bolted RPC plate under direct tension, Journal of Structural Engineering (Madras), 2009, 36(5), pp. 333–341

[15] MOHAN, A., TABISH HAYAT, M.: Characterization of mechanical properties by preferential supplant of cement with GGBS and silica fume in concrete, Materials Today: Proceedings, 2020, 43, pp. 1179–1189.

[16] DHARMAR, S., GOPALAKRISHNAN, R., MOHAN, A.: Environmental effect of denitrification of structural glass by coating TiO2, Materials Today: Proceedings, 2020, 45, pp. 6454–6458

[17] CHEONG,K.H.ANDLEE,S.C:"StrengthofRetemperedConcrete",ACIMaterialsJ.90(3),203-206 (1993)

[18] KIRUTHIKA, C., LAVANYA PRABHA, S., NEELAMEGAM, M.: Different aspects of polyester polymer concrete for sustainable construction Materials Today: Proceedings, 2020, 43, pp. 1622–1625

[19] PRABHA, S.L., SURENDAR, M., NEELAMEGAM, M.: Experimental investigation of eco-friendly mortar using industrial wastes ,Journal of Green Engineering, 2019, 9(4), pp. 626–637

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