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A Numerical Analysis of The Modulus of Elasticity of The Graded Concrete

M. Mirza Abdillah Pratama[1)]
Civil Engineering Department
Universitas Negeri Malang

Buntara Sthenly Gan[2)]
Architecture Department
Nihon University, Japan

Han Ay Lie[3)]
Civil Engineering Department
Universitas Diponegoro

Andika Bagus Nur Rahma Putra[4)]
Mechanical Engineering Department
Universitas Negeri Malang

***Abstract*— Graded concrete is one of the functionally graded materials in civil engineering that can reduce the use of cement to create a high-performance structural element. The graded concrete is formed by combining two distinguish concrete mixes or more which have different strength so that the elements with varying material properties in a certain direction are obtained. The results of previous studies stated that the concrete compressive strength of the graded concrete was determined by the lowest strength while the studies discussing the resulting modulus of elasticity had not been conducted intensively. This research aimed to analyse the effect of concrete strength disparity in graded concrete to the modulus of elasticity. Six concrete cylindrical models were analysed using the Strand7 programme to obtain the stress-strain relationship on compression. The data is then analysed to obtain the modulus of elasticity of each model. The results show that the graded concrete can increase the modulus of elasticity of the concrete, and can be further improved by combining two drastically different concrete strength. The application of graded concrete can increase the serviceability level of structural elements and reduce the deflection due to working loads.**

Keywords: Graded concrete, functionally graded materials, compressive strength, modulus of elasticity

I. INTRODUCTION

Modulus of elasticity is one of the characteristics of the material that contribute to resisting elastic deformation due to workload [1-2]. In the analysis, modulus of elasticity can be calculated by comparing the stress to the strain of the material due to axial loading test under elastic condition. In concrete materials, concrete elastic stress is assumed as equivalent as 30% of peak load. In this condition, concrete is considered to undergo a linear behaviour so material stiffness stays constant since the crack has not formed. The modulus of elasticity is closely related to the stiffness of structural members [3-4]. In further analysis, structural rigidity is highly related to the magnitude of the deflection during loading. The higher the modulus of elasticity of the material, the greater the stiffness of the resulting structure so that the resulting deflection will be much minimum [5].

The results of the previous experimental research show that the modulus of elasticity of concrete can be increased by applying the concrete gradation scenarios on reinforced concrete elements. Preliminary experimental tests on concrete cylinders show that the modulus of elasticity of the graded concrete is equivalent to that produced by the high strength concrete, but with more efficient use of materials [6-7]. The use of graded concrete in structural elements is predicted to reserve the use of cement by 50 per cent so that construction will be less cost [8-9]. In this study, investigations focussing on the effect of the concrete strength difference in the graded concrete to the modulus of elasticity were carried out numerically using the finite element analysis programme.

II. RESEARCH METHODS

In this study, researchers used the Strand7 programme to model and to analyse the testing specimens. The programme features the non-linear analysis so it is suitable for modelling concrete material. The models consist of two groups, namely the testing models and the controlling model. The testing model consists of six types of graded concrete specimens that combine the different concrete strength, which are 24.7 - 30 MPa; 24.7 - 40 MPa; 24.7 - 50 MPa; 24.7 - 57.2 MPa; 24.7 - 60 MPa; and 24.7 - 70 MPa. The controlling model is a normal concrete model with a uniform strength of 24.7 MPa. All models are represented as cylindrical specimens and are further approached using the axisymmetric model to reduce the number of degree of freedoms. The axisymmetric models allow the circular-shaped specimens simplified in a 2-dimensional model with the boundary conditions adjusted to obtain the representative behaviour during testing as the experimental method. Concrete cylinders were tested under uniaxial compression test to obtain the stress and strain relationship. The loading is input by assigning the displacement load in the upper nodes by 1 mm downward (Y-) while the nodes on the bottom side are given boundary conditions so the nodes are able to move horizontally during load applied [10]. The stress-strain of concrete is constructed in accordance with CEB-FIB Model Code 2010 recommendations. The modelling of graded concrete in this research is shown in Figure 1.

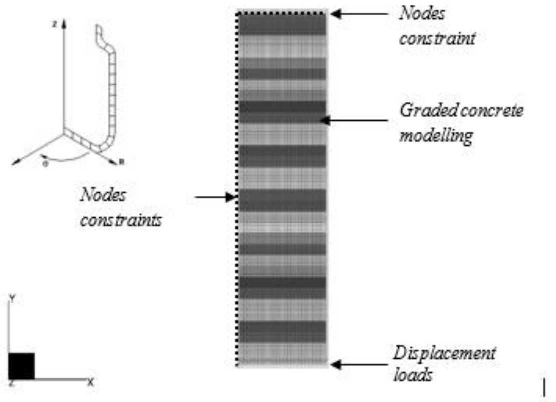

Figure 1. Modelling of testing model of graded concrete in Strand7

III. RESULTS AND DISCUSSION

The Strand7 analysis results in the reading of displacement and load working on each model analysed. The total load on each loading step is obtained by summing the reaction of nodes located at the end support, while the displacement is read from a representative nodal in the free support of each model. The load-deformation relationship of each testing model is shown in Figure 2. Figure 2 shows that the load-deformation curve of 24.7 - 70 MPa model has a more upright slope than 24.7 - 30 MPa.

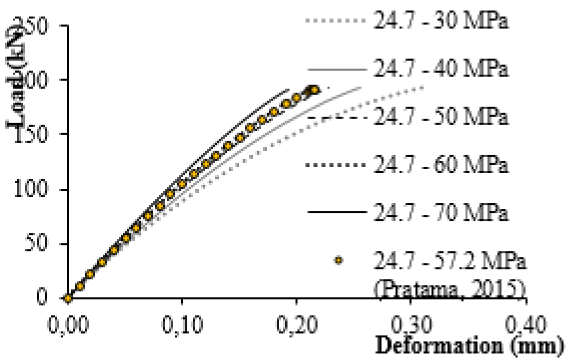

Figure 2. Load-deformation relationship of graded concrete

The load-deformation graphs (Figure 2) are then transformed to the stress-strain relationship so that the effect of the compressive strength ratio of concrete used on the graded concrete to the modulus of elasticity could be studied. The concrete stress can be analysed by comparing load reaction on each loading step to the area of the model. The strain is obtained by dividing the specimen deformation at each load increment to the initial specimen height. The data are then charted to obtain a graph of the concrete stress-strain relationship (Figure 3).

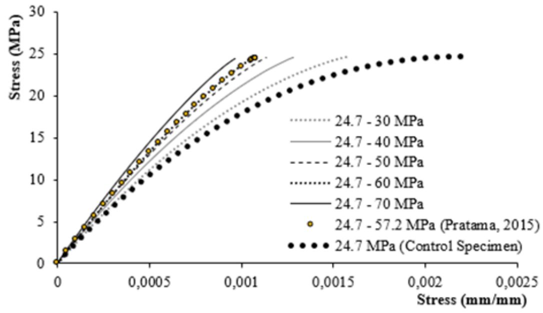

Figure 3. Stress-strain relationship of graded concrete and controlling specimen

Figure 3 shows that the stress-strain curves of the testing models have a different gradient. The 24.7 MPa controlling model has the lowest gradient compared to the 24.7 - 70 MPa graded concrete. Even so, all of the testing models have similar compressive strength, only with varying peak strain values. Because the normal concrete has the most collapsed graph, this specimen has the highest peak strain compared to the others, 0.0022. The graded concrete 24.7 - 70 MPa has the least peak strain of 0.0009. Based on the analysis results, the graded concrete with a significant difference in compressive strength changes material behaviour from ductile to more brittle. On the other hands, the change of material behaviour undergoes simultaneously with the increase of modulus of elasticity.

The modulus of elasticity of the graded concrete in this study was carried out by calculating the secant modulus of each stress-strain curve. The observation was conducted at 30% peak load or equivalent to 7 MPa. The reading of concrete strain at the 30% peak load of 24.7 MPa; 24.7 - 30 MPa; 24.7 - 40 MPa; 24.7 - 50 MPa; 24.7 - 57.2 MPa; 24.7 - 60 MPa; and 24.7 - 70 MPa models are 0.00031; 0.00029; 0.00027; 0.00026; 0.00025; 0.00025; and 0.00023; so that the resulting elastic modulus is 22,317.7 MPa; 23,745.7 MPa; 25,729.3 MPa; 27,605.2 MPa; 27,197.0 MPa; 27,983.1 MPa; and 30,500.2 MPa. The results show that the modulus of elasticity of concrete increases by applying the concept of strength gradation in the specimen. The most drastic increment of the modulus of elasticity is obtained from graded concrete model composed with a significant difference of concrete strength. The data recapitulation of the analysis can be seen in Table 1.

Table 1. The graded concrete compressive strength and modulus of elasticity

Models	Lowest concrete strength (MPa)	Highest concrete strength (MPa)	Graded concrete strength (MPa)	Modulus of elasticity of graded concrete (MPa)
24.7 MPa (Controlling specimen)	24.7	24.7	24.7	22,317.7
24.7 - 30 MPa	24.7	30	24.6	23,745.7
24.7 - 40 MPa	24.7	40	24.5	25,729.3
24.7 - 50 MPa	24.7	50	24.5	27,197.4
24.7 - 57.2 MPa (Pratama, 2015)	24.7	57.2	24.5	27,861.6
24.7 - 60 MPa	24.7	60	24.4	27,983.1
24.7 - 70 MPa	24.7	70	24.4	30,500.2

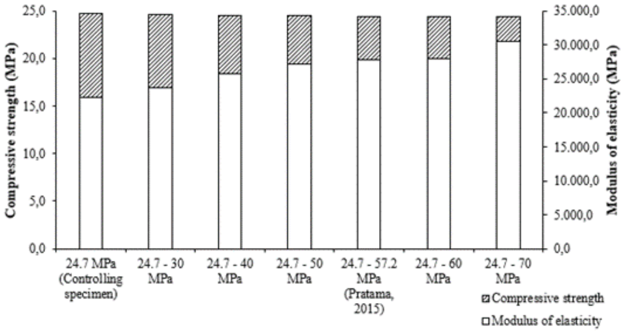

Figure 4. Compressive strength and modulus of elasticity of graded concrete and controlling specimen

The influence of concrete strength disparity to the resulting compressive strength and the modulus of elasticity is shown in Figure 4. The data shows that the use of drastically different concrete strength in the graded concrete can increase the modulus of elasticity up to 37% compared to the normal concrete. When the graded concrete is applied to building structural elements, it could reduce the deflection so that the level of serviceability improved. This is because the modulus of elasticity of concrete corresponds to the parameters that determine the amount of deflection in an element.

The more significant the concrete strength different, the resulting modulus of elasticity increases by this trend (Figure 5). The use of concrete with a threefold difference in compressive strength potentially increase the modulus of elasticity by up to one and a half times that of normal concrete. This gradation concrete is considered very beneficial because the level of serviceability increases with the use of minimum cementitious materials.

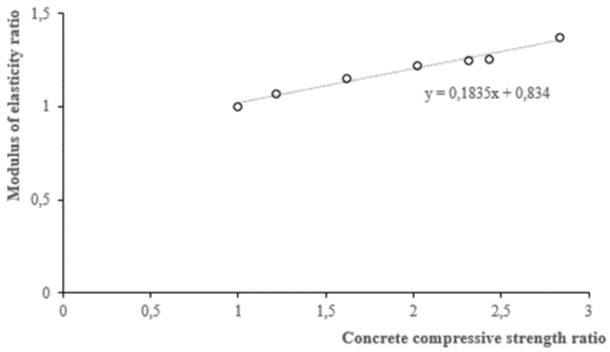

Figure 5. Concrete compressive strength ratio to the modulus of elasticity ratio

IV. CONCLUSION

Numerical research results show that the use of concrete gradation can significantly improve the performance of the modulus of elasticity of the concrete. The improvement in modulus of elasticity is up to one and a half times by utilizing concrete with a difference in compressive strength three times. The results of the analysis also showed that the concrete gradation with a drastic concrete strength difference could change the element failure from the ductile condition to be more brittle because the concrete peak strain was reduced. The use of reinforcing bars in a structural element could overcome this issue.

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