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Reinforced Concrete Ring Beams [Non-Linear Finite Element Analysis (NLFEA)]

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ABSTRACT

Ring beams are encountered in dome, circular reservoir and silo structure. Reinforced concrete ring beams supported by equally spaced columns have been used for the construction of silo structure, where the large free space is needed at the ground level. In this paper, three reinforced concrete ring beams supported on four equally spaced columns have been analyzed by using non-linear finite element analysis (NLEFA) to predict the ultimate strength, mechanism of failure, crack pattern and deformed shape. The geometrical and material properties of the ring beams are similar except of its cross sectional depth and the properties of reinforcements. The NLFEA results indicate that the failure modes of the ring beams are dependent on its (depth/span) ratio (the span/depth ratio has been taken as straight beams). The tension stiffening value from 0.002 to 0.003 is suggested to use in the non- linear finite element analysis (NLFEA) of ring beams.

KEYWORDS: *Ring beams, Geometrical properties for ring beams, Analysis Ring beams, Failure in Ring beams, Ring beams criteria, Non-linear FEM*

1. INTRODUCTION

Curved in plan beams structure frequently used for balcony in building, sometimes on bridge structure and others. Meanwhile, ring beams with full circular in plan are mostly encountered in dome, circular reservoir, silo, offshore structure and others. The deep ring beams have been used by industries due to its high loading resistance.

Ring beams are mostly act by uniform distributed load, for example as load transferred from dome of structure .In practice, ring beams are rarely to be used to support point loading.

Steel beams have been applied to some curved structure, but mostly reinforced concrete has been practice for most of the deep ring beams due to ease of constructing.

The failure mode, cracking pattern, ultimate load of reinforced concrete ring beams at ultimate state are effected by lateral loading on the ring beams has not clearly been understood. It normally occurring on deep reinforced concrete ring beams.

Material response characteristics for element used in modeling will highly influence the results of the non-linear finite element analysis (NLFEA) [1].Thus, the material properties for concrete and reinforcement proposed by researchers in the past and BS8110: Part 1 and Part 2 has been studies to find the simple and suitable stress-strain curve of these material for the non- linear finite element analysis (NEFAE). The tension softening for concrete to obtain the ring beam response is stressed in this paper. Variation of tension stiffening parameter has been applied for each ring beams model during NLFEA [2].This paper has indicated that the failure modes of the ring beams are dependent on its (depth/span) ratio for curve beam.

1.2 REVIEW OF LITERATURE

The finite element method can be regarded as an extension of the displacement method for beam and frames to two and three dimensional continuum problems, such as plates, shells and solid structures [6].The actual continuum is replaced by an equivalent idealized structure composed of discredited elements connected together at finite element number of nodes [7].

Marsono (2000) has test eleven finite element models failure and analyzed NLFEA. The concluded that the maximum load and mode of failure of coupled shear walls test specimens can be verified by calibrating and tuning the concrete finite element parameters to trace the shear wall behavior as observed in the laboratory. Also found that the value assigned to the concrete parameters would significantly influence the NLFEA results.

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From the results reported by researchers in the past, it can be concluded that NLFEA is suitable to be used for reinforced concrete structural analysis or detail study, besides an expensive laboratory experiment .The material response characteristics of concrete and reinforcement used in NLFEA will highly influence the structural behavior. Therefore, NLFEA should not recommended to be used alone to predict structure behavior without prior experimental or theoretical background [1].

1.1 Objectives and Scope of Study

The general aim and objectives of this study are:

1. To analyze reinforced concrete ring beams to predict, a) ultimate load, b) mechanism of failure, c) crack patterns and, d) deformed shape.
2. To compare the failure mode of shallow and deep ring beams.
3. To develop a range of tension parameter stiffness for deep ring beams of the non- linear finite element analysis (NLFEA).

The structural geometry of ring beams under this study is the ring beams supported by four columns. Only the uniform distributed load was applied for the non- linear finite element analysis (NLFEA) of ring beams. There are various parameters for concrete and steel material properties that affect the solution of the non- linear finite element analysis (NLFEA), but only the range of tension stiffening for concrete will be studied, and proposed for ring beams NLFEA computer software for the modeling.

2.0 Analysis of Ring Beams and Curved beams

Curved beams are subjected to torsional moments in addition to shear and bending because the centre of gravity of loads does not coincide with the centre line axis of the member. The torsional moments cause overturning of the beam also unless the ends of the beams are properly restrained. Hence; such beams have to be designed for bending moment, shear force and torsional moment. Typically torsional moment is converted into equivalent shear.

Typically torsional moment is converted into equivalent shear.

Safarian et al., reported that the analysis method using geometry approach for ring beams loaded with uniform distributed load. The concluded that if circular beams or ring beams supported over evenly spaced columns, the torsion at the center of the beam between any two adjacent supports shall be zero and also there will be no such moments at support itself .Thus, the support section of the beam shall be designed for bending moment and shear force only[22].

Table 2.1 Coefficients for bending moment at support, mid span and torsion in circular Beams [2].

Number of support	θ°	*K1*	*K2*	*K3*	Value of ϕ for maximum twisting moment(°)
4	90.0°	0.137	0.070	0.021	19.25°
5	72.0°	0.108	0.054	0.014	15.75°
6	60.0°	0.089	0.045	0.009	12.75°
7	51.4°	0.077	0.037	0.007	10.75°
8	45.0°	0.066	0.030	0.005	9.50°
9	40.0°	0.060	0.027	0.004	8.50°
10	36.0°	0.054	0.023	0.003	7.50°
12	30.0°	0.045	0.017	0.002	6.25°

Syal and Goel (1984) summary the analysis in three equations as below, with the bending moment at support or mid-span and the maximum torsion can be calculated by the coefficient Table 2.1. In all equation ,the parameter of the equation below (**W**) is uniform distributed load, **R** is the radius of ring beams , **θ** (in radians) is angle subtended at the centre by two consecutive support and **K** coefficient for bending moment (See Figure 2.1)[22].

$$\text{Support moment} = \mathbf{K1*W*R^2\ \theta} \quad (1)$$

$$\text{Mid –span moment} = \mathbf{K2*W*R^2*\ \theta} \quad (2)$$

$$\text{Maximum torsion} = \mathbf{K3*W*R^2\ *\theta} \quad (3)$$

2.1 Behaviour of Deep Beam

Macgregor, J.G.(1997) define a deep beam is a beam in which a significant amount of the load is carried to the support by compression thrust joining the load and the reaction .This behavior of beam will happen if a concentrated load acts closer than about 2d to the support, or for uniformly loaded beams with a span/depth ratio, less than about

4 to 5 [18] . The influence of column stiffness on the discontinuity forces between ring beam and column in silo design method by Safarian and Harris (1984). He concluded that the design of the ring beam and columns and the connection between these two members could then be performed more economically [11].

The transition from ordinary beam behavior to deep beam behavior is imprecise .For design purpose, it is often considered to occur in a ratio of about 2.5. The CIRIA guide gives most comprehensive recommendations and is the only one that covers the buckling strength of slender beams [8].

CIRIA Guide 2 provides simple rules for designing the simple forms of reinforced concrete beams, which are deep in relation to their span, i.e. beams with a span/ratio of less than 2 for single beams or less than 2.5 for continuous beams.

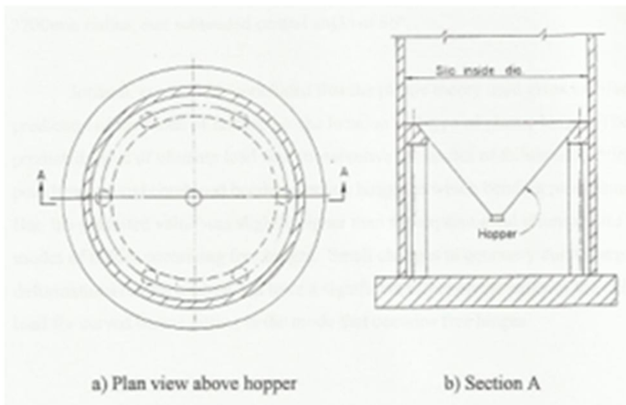

Figure 2.1 Concrete ring beam columns supporting a conical hopper

Rogowsky , give the description of the behavior of typical deep beam test specimen as illustrated in figure 2.2.In general ,deep beams develop little initial flexural cracking, mid span flexural cracks tended to form before negative beam is the development of diagonal ,inclined or shear cracks which occur suddenly ,this can occurred at about 50% of the ultimate load. As the load increased, additional flexural crack formed. Yield of the main flexural reinforcement brings about significant defalcations. These deflections are accompanied by joint rotation, so called truss, which eventually causes the concrete compression struts to rail. The strength of the member is governed by the yield of the main flexural reinforcement while ductility is governed by failure of the concrete [18].

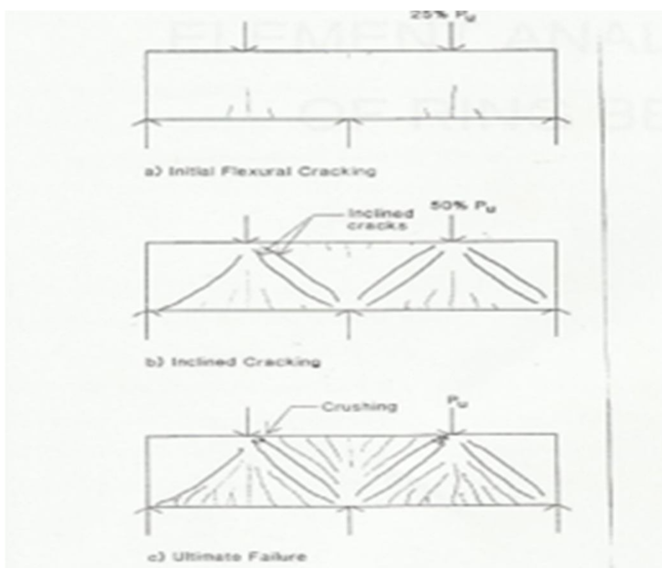

Figure 2.2 Typical continuous deep beam cracking behaviour

3.0 Non-linear Finite Element Analysis for Control Models

For the purpose of verification to the results of ring beams models, three control models have been developed by using the same materials response characteristic for concrete and reinforcing steel. In NLFEA of these three control models ,SOLID elements has been used to model concrete element and TRUSS 3D has been used to model reinforcing steel.

3.1 Control Model 1

For control Model 1, a concrete cube of 150 mm width, length and height has been modeling into 512 elements of SOLID 3D by 8x8x8x finite element mesh. The load was applied as pressure on the top surface of concrete cube model. In the NLFEA modeling, the pressure has been idealized as point loads acting on the concrete surface .The point loads at concrete of top cube surface have been left out during the modeling to avoid concentration at the corners and casual local failure.

3.2 Control Model 2

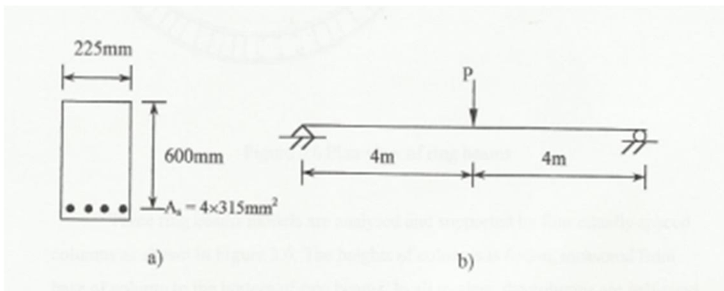

Figure 3.1 a) Beam cross section of control model 2, b**)** Structural boundary and loading condition for control model 2

3.3 Structural Geometry of Ring Beams Models

Three Ring Beams models are analyzed and supported by four columns as shown in figure 3.2, the heights of columns is h=3 m measured from the base of column to the bottom of ring beams.

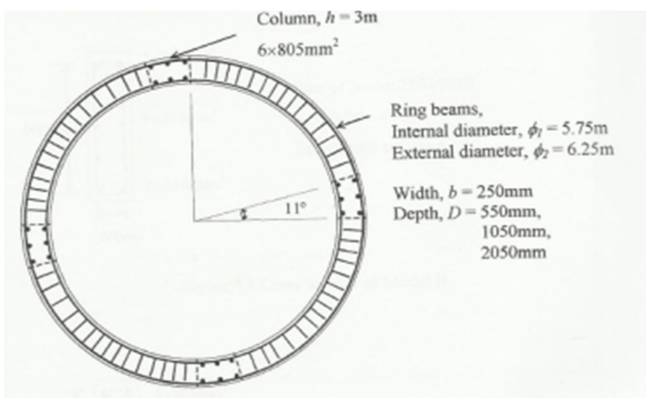

Figure 3.2 Plan view of ring beams

All models has a similar and breadth of ring beams, columns and height of columns as a supported. The only differences are the depth of beam and the percentage of main reinforcement as shown in figures 3.3 to 3.6.

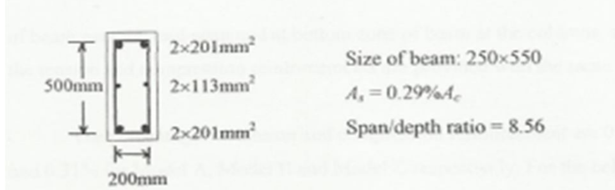

Figure 3.3 Cross section beam of Model A

The second control model consisting of plain concrete beam, SOLID 3D element has been used to model this concrete beam. There are 360 elements of SOLID have been used .The cross section in figure 3.1 a and 3.1 b respectively. The beam is simply supported and a concentrated load is applied at its mid span.

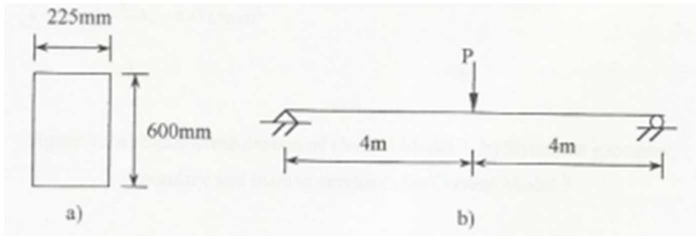

Figure 3.4 a) Beam cross section of control model 3, b**)** Structural boundary and loading condition for control model 3

3.4 Control Model 3

The under-Reinforced concrete beam has been choosing as control Model 3. The cross–section area reinforced concrete beam and the areas of tension reinforcement are shown in figure 3.2 (a). The cross-section area of concrete is 225 mm x 600 mm with the concrete covers has been neglected. The reinforcement bars are modeled at the bottom of the concrete elements. In this model, concrete element is modeled with 360 elements of SOLID and reinforcement is modeled with 120 elements of TRUSS 3D.

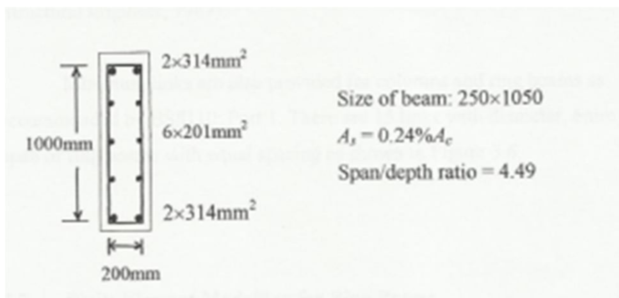

Figure 3.5 Cross section beam of model B

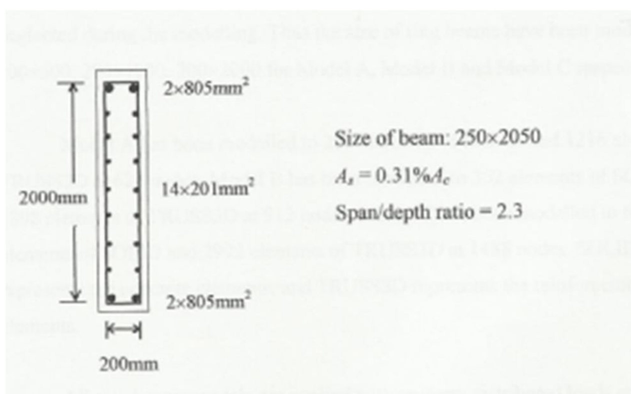

Figure 3.6 Cross section beam of Model C

The amount of main reinforcement provided to each ring beams models are the minimum percentage of compression reinforcement that is 0.2% as recommended. Because of the compressive reinforcement is needed at top zone of beam near the mid –span and at bottom zone of beam at the columns. Subsequently the tension and compression reinforcements are provided with the same percentage.

The percentages of tension and compression reinforcement are 0.29%.0.24% and 0.31% for Model A, Model B and Model C respectively. For the columns, the percentage of reinforcement is 2.79% to increase the stiffness of columns. The side lacers are also provided to all models with maximum pitch of 250mm (Institution of Structural Engineer, 1989).

Minimum links are also provided for columns and ring beams as recommended by Euro code. They are 15 links with diameter 6 mm at each span of ring beams with equal spacing as shown in figure 3.3.The concrete cover for steel bars in ring beams as well as columns were neglected during the modeling ,thus the size of ring beams have been modeled are showed in figures 3.3 to 3.6.

3.5 Load Increment Medellin for NLFEA

Basically, there are three incremental control techniques can be used in NLFEA, that is force, Displacement, Control and Riks Arc-length Control. In this paper the Riks Arc –length control has been used for NLFEA of all models. The loads are increased step by step depend to the arc length parameter and the structure is analyzed for each loading increment .Newton-Raphson Iteration has been used as the solution method to obtain the NLFEA failure load.

3.5.1 Riks Arc-length Control

In Riks Arc –Length Control, a special parameter is prescribed by consistent (auxiliary) equation ,which is added to the set of governing equations of the equilibrium of the system. In this technique ,the load pattern is applied loads in proportional increment (using a single load multiplier) to achieve an equilibrium under the control of a specified length (arc-length) in the equilibrium path. The arc-length will be automatically re-calculated by the program, where no “time” curve is required. The analysis will be terminated by either of these controls being exceeded,

i)The Maximum Load-pattern multiplier (Value used=1 x10^8)
ii)The Maximum value of any DOF (Value used =500)
iii)The Maximum number of arc steps (Value used=500)

4.0 Results of Non-linear Finite element Analysis

4.1 Results of Control Model 1

The minimum principal stress,P3 contour for Control Model 1 is shown in the figure 4.1. from the NLFEA, the extreme minimum principal stress for concrete element is -34.8 N/mm^2. The load of this concrete model is 701.9 kN when the concrete crashes in compressive.

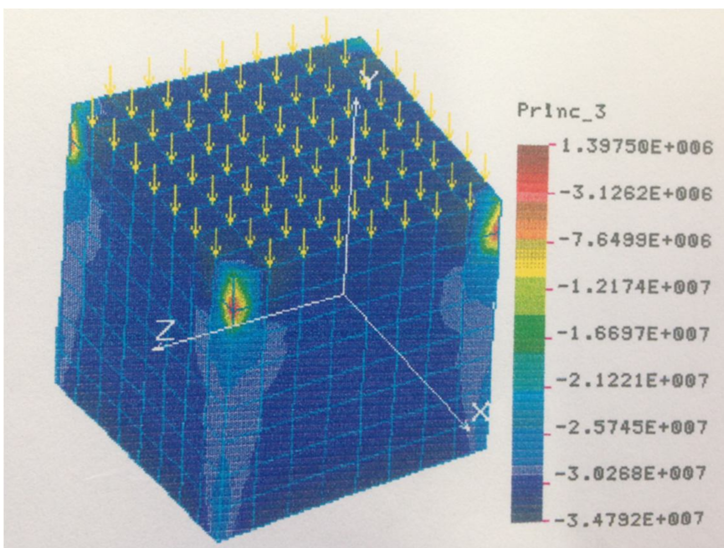

Figure 4.1 Minimum principal stress, P3 contour of Control Model 1

4.2 Results of Control Model 2

The ultimate concentrated load at mid –span of Control Model 2 is 41.4 kN. The maximum principal stress, P1 contour and vector plot for Control Model 2 is shown in Figure 4.2 and 4.3 respectively .The extreme maximum principal stress for concrete element is 4.3 N/mm^2 , and the located at the bottom part of beam mid-span.

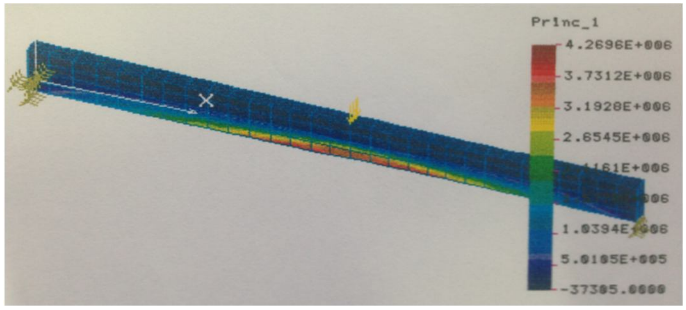

Figure 4.2 Maximum principal contour plot of concrete element for Control Model 2

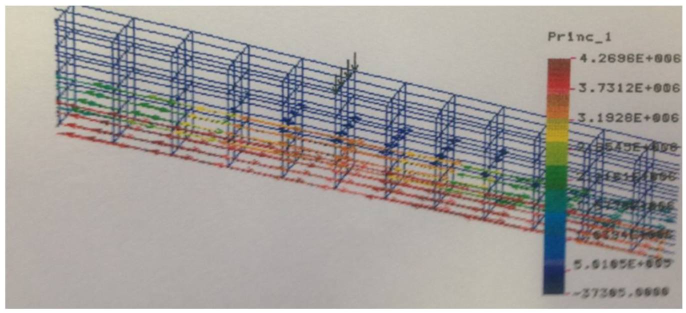

Figure 4.3 Maximum principal stress, P1 of concrete element for Control Model 2

4.3 Results of Control Model 3

The ultimate concentrated load at mid span of Control Model 3 is 146.4 kN. The maximum principal stress ,P1 contour plot for concrete is shown in figure 4.4 the extreme maximum principal stress for concrete is 4.6 N/mm2.The normal stress ,SX contour plot for reinforcements is shown in Figure 4.5 ,and the extreme stress for reinforcement is 415.6 N/mm^2 near to mid –span, the steel is assumed has yielded.

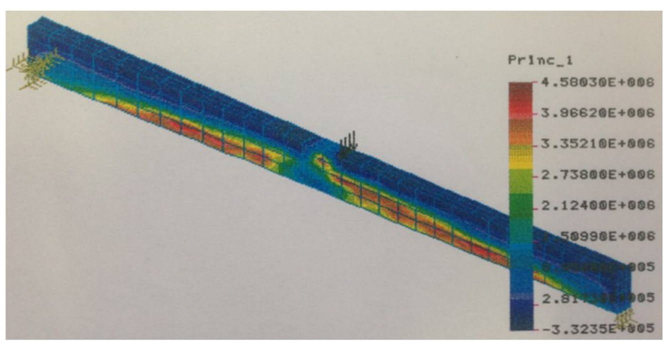

Figure 4.4 Maximum principal stress,P1 contour of concrete plot of concrete elements for control Model 3

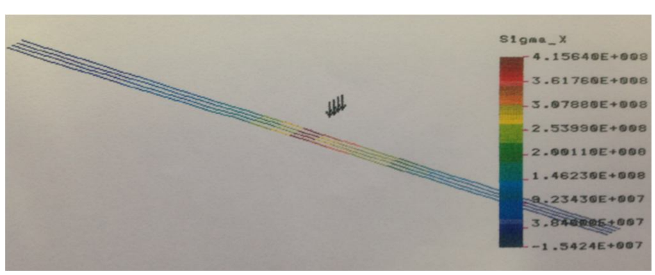

Figure 4.5 Normal stress, SX contour plot of reinforcement elements for Control Model 3

Figures 4.6 and 4.7 showed the maximum and minimum principal, P1 and P3 vector for concrete element respectively. The extreme minimum principal stress vector plot for concrete is -25.6 N/mm^2 occurs at the top part of the beam at mid span.

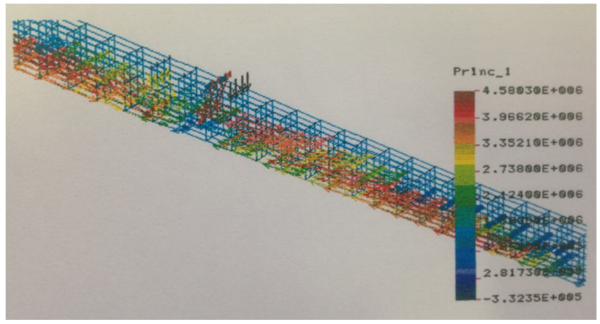

Figure 4.6 Maximum and minimum principal stress P1, vector for concrete element

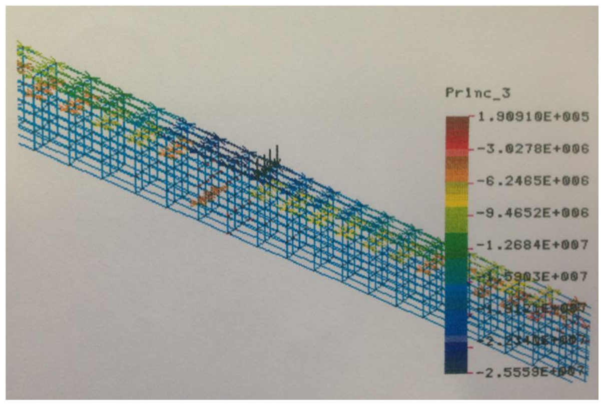

Figure 4.7 Maximum and minimum principal stress P3, vector for concrete element

4.4 Results of Ring Beam Model A

The results as shown in table 4.1 for model A for various tension stiffening values. Table 4.1 showed the extreme results at maximum and minimum principal stress,P1 and P3 of concrete. Normal stress, SX for reinforcing steel are also shown at various tension stiffening during NLFEA for model A .

Table 4.1 Results of Model A for various tension stiffening values

Tension stiffening (Max are step)	**Results output**			
	Principal stress for concrete (N/mm^2)		**Nominal stress, SX for reinforcement (N/mm^2)**	**Ultimate load (kN/m)**
0.0010 (155)	Maximum,P1 Minimum,P3	5.6 -7.7	222.8 -77.5	62.6
0.0012 (166)	Maximum,P1 Minimum,P3	5.2 -8.8	276.0 -89.5	68.8
0.0014 (165)	Maximum,P1 Minimum,P3	4.9 -9.9	290.5 -102.3	75.8
0.0016 (179)	Maximum,P1 Minimum,P3	4.8 -10.8	359.8 -111.0	81.5
0.0018 (193)	Maximum,P1 Minimum,P3	4.9 -11.7	394.7 -120.9	87.5
0.0019 (176)	**Maximum,P1 Minimum,P3**	**4.9 -12.2**	**400.3 -126.2**	**90.3**
0.0020 (210)	Maximum,P1 Minimum,P3	5.0 -12.6	400.2 -130.4	92.5
0.0022 (203)	Maximum,P1 Minimum,P3	5.2 -12.4	398.4 -127.1	92.7
0.0023 (201)	Maximum,P1 Minimum,P3	5.3 -13.4	400.2 -139.8	97.6
0.0024 (276)	Maximum,P1 Minimum,P3	5.4 -13.6	400.3 -142.3	99.0
0.0025 (212)	Maximum,P1 Minimum,P3	4.9 -9.6	415.7 -92.3	72.0
0.0026 (500)	Maximum,P1 Minimum,P3	5.5 -13.8	401.8 -144.3	100.9

Figures 4.8 to 4.13 showed the results of NLFEA at tension stiffening of 0.0019. The maximum principal stress, P1 contour and vector plot for concrete element is shown in figure 4.8 and 4.9 respectively .The extreme maximum principal stress of concrete element is 4.9 N/mm^2 .

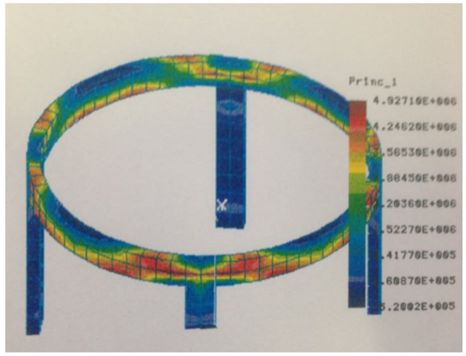

Figure 4.8 Maximum principal stress, P1 contour plot of concrete elements for Model A

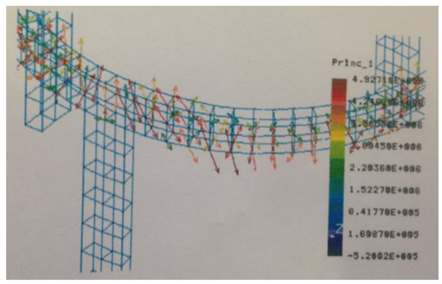

Figure 4.9 Maximum principal stress, P1 vector plot of concrete elements for Model A

Figure 4.10 showed the normal stress, SX contour plot for reinforcement element .The maximum tension stress is 400.3 N/mm^2 and the maximum compression stress is – 126.2 N/mm^2. Figure 4.11 shown the minimum principal stress ,P3 contour plot for concrete element, and the extreme minimum principal stress for concrete elements is -12.2 N/mm^2 .

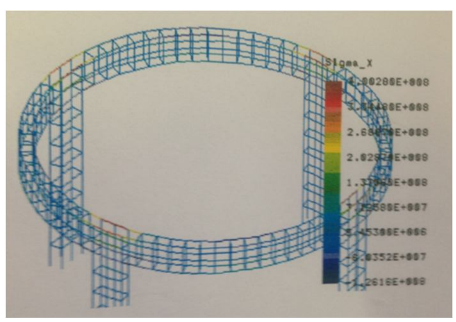

Figure 4.10 Normal stress, SX contour plot of reinforcement elements for Model A

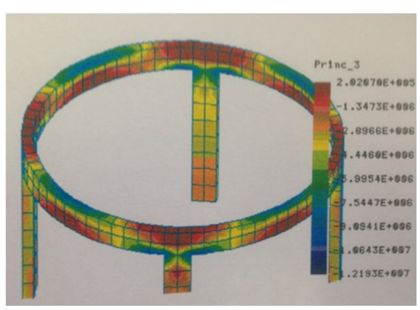

Figure 4.11 Minimum principal stress, P3 contour concrete elements for model A

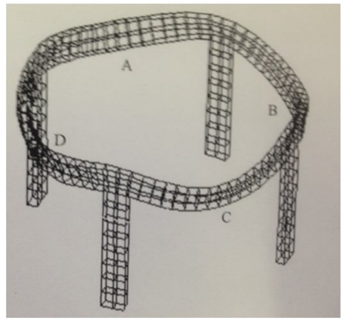

Figure 4.12 Deformed shape for model A as ultimate load

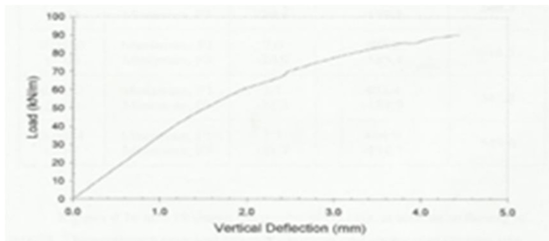

Figure 4.13 Load versus deflection at mid-span at point A,B,C and D for Model A

4.5 Results of Ring Beam Model B

Table 4.2 shows the extreme results of maximum and minimum principal stress, P1 and P3 of concrete, and normal stress, SX for reinforcing steel at using various tension stiffening during NLFEA for Model B.

Table 4.2 Results of Model B for various tension stiffening values

Tension stiffening (Max are step)	Results output			
	Principal stress for concrete (N/mm^2)		Nominal stress,SX for reinforcement (N/mm^2)	Ultimate load (kN/m)
0.0010 (180)	Maximum,P1 Minimum,P3	4.8 -11.5	173.8 -85.2	193.8
0.0020 (193)	Maximum,P1 Minimum,P3	5.8 -17.1	276.0 -89.5	278.2
0.0025 (198)	Maximum,P1 Minimum,P3	6.5 -19.3	318.3 -140.2	313.0
0.0028 (201)	**Maximum,P1 Minimum,P3**	**4.8 -10.8**	**402.9 -179.1**	**328.3**
0.0030 (203)	Maximum,P1 Minimum,P3	6.8 -20.4	403.2 -185.4	336.5
0.0032 (202)	Maximum,P1 Minimum,P3	7.0 -20.9	403.4 -189.9	343.8
0.0034 (204)	Maximum,P1 Minimum,P3	7.3 -21.7	404.0 -194.3	349.8

Figures 4.14 to 4.19 showed the results of NLFEA at tension stiffening of 0.0028 .The maximum principal stress,P1 contour and vector plot for concrete elements is shown in figures 4.14 and 4.15 respectively. The extreme maximum principal stress of concrete is 6.8 N/mm^2

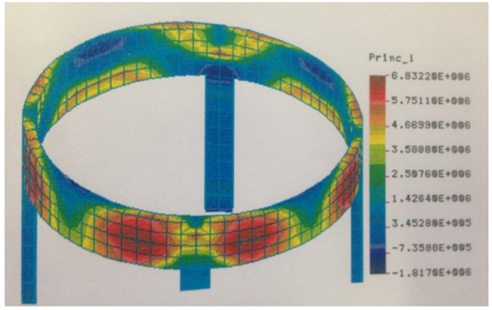

Figure 4.14 Maximum Principal stress**, P1** contour plot of concrete elements for Model B

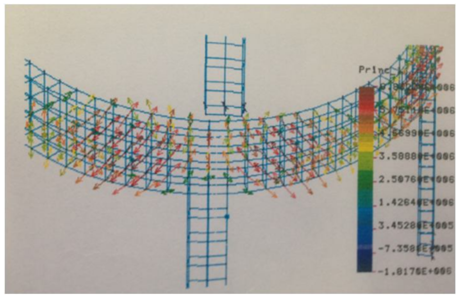

Figure 4.15 Maximum principal stress, P1 vector of elements for Model B

Figure 4.16 showed the normal stress, SX contour plot for reinforcement element, with the maximum tension stress is 402.9 N/mm2 and maximum compression stress is -179 N/mm^2 .Figure 4.17 showed the minimum principal stress,P3 contour plt for concrete elements ,and the extreme minimum principal stress for concrete is -20.4 N/mm^2.

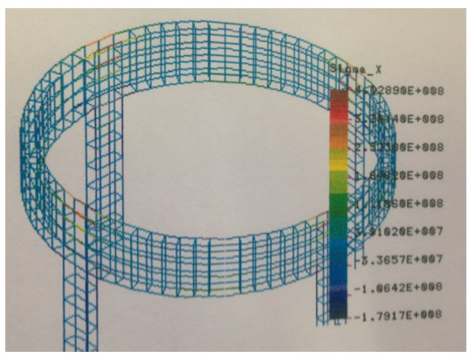

Figure 4.16 Normal stress, SX contour plot of reinforcement elements for Model B

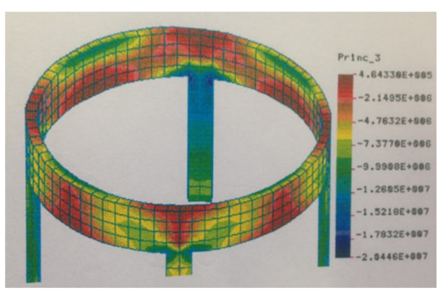

Figure 4.17 Minimum principal stress, P3 contour plot of concrete elements for Model B

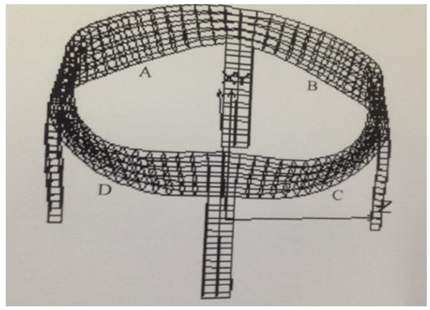

Figure 4.18 Deformed shape for Model B at ultimate load

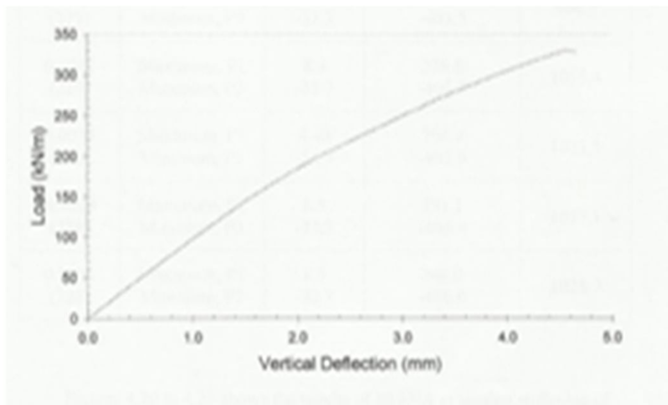

Figure 4.19 Load versus vertical deformed at mid-span at point A,B,C and D

4.6 Results of Ring Beam Model C

Table 4.3 shows the extreme results of maximum and minimum principal stress, P1 and P3 concrete and normal stress, SX for reinforcing steel at various tension stiffening during NLFEA for model C .

Table Table 4.3 Results of Model C for various tension stiffening values

Tension stiffening (Max are step)	**Results output**			
	Principal stress for concrete (N/mm^2)		**Nominal stress,SX for reinforcement (N/mm^2)**	**Ultimate load (kN/m)**
0.0008 (219)	Maximum,P1 Minimum,P3	6.4 -29.5	241.7 -333.3	803.2
0.0009 (221)	Maximum,P1 Minimum,P3	6.9 -31.0	271.3 -374.6	872.2
0.0010 (221)	Maximum,P1 Minimum,P3	7.5 -32.4	321.8 -374.6	872.2
0.0011 (228)	Maximum,P1 Minimum,P3	7.5 -32.4	321.8 -401.1	938.0
0.0011 (227)	Maximum,P1 Minimum,P3	8.1 -33.2	271.4 -403.5	996.3
0.0012 (176)	Maximum,P1 Minimum,P3	8.3 -33.7	276.8 -405.7	1015.4
0.0014 (236)	Maximum,P1 Minimum,P3	8.43 -33.7	266.9 -405.9	1025.5
0.0020 (228)	**Maximum,P1** **Minimum,P3**	**8.5** **-33.7**	**251.1** **-405.9**	**1027.1**
0.0025 (228)	Maximum,P1 Minimum,P3	8.5 -33.7	246.0 -406.0	1028.7

Figures 4.20 to 4.25 **s**howed the results of NLFEA at tension stiffening of 0.002. The maximum principal stress,P1 contour and vector plot for concrete element is shown in figure 4.20 and figure 4.21 respectively .The extreme maximum principal stress for concrete element is 8.5 N/mm^2.

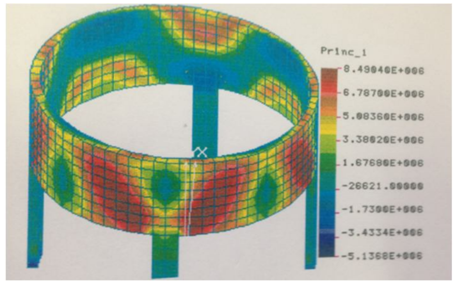

Figure 4.20 Maximum principal stress,P1 contour plot for concrete element for Model C

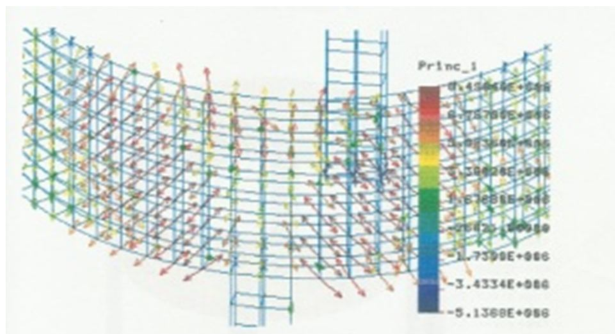

Figure 4.21 Maximum principal stress, P1 contour plot for concrete element for Model C

Figure 4.22 showed the normal stress, SX contour plot for reinforcement element .For reinforcements, the maximum tension stress is 251.1 N/mm^2 and the maximum compression stress is – 405.9 N/mm2 .Figure 4.23 shows the minimum principal stress, P3 contour plot element, and the extreme minimum principal stress for concrete elements is -33.7 N/mm^2 .

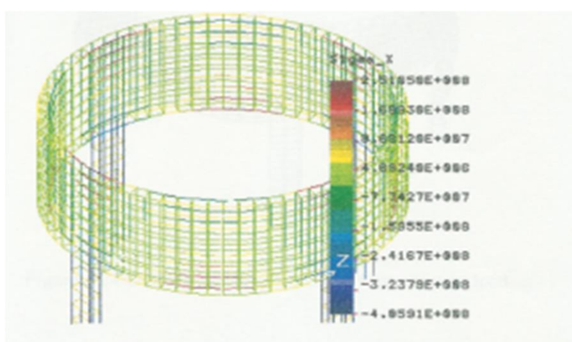

Figure 4.22 Normal stress, SX contour plot of reinforcement element for Model C

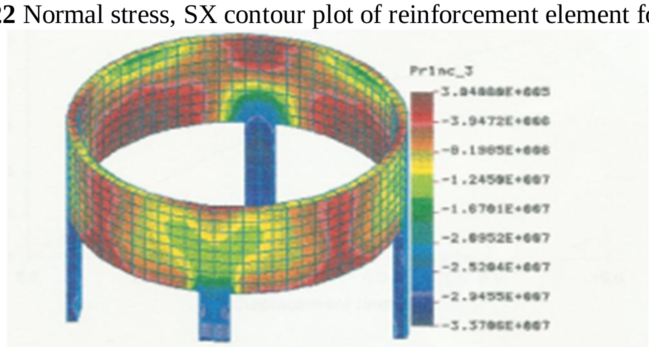

Figure 4.23 Minimum principal stress, P3 contour plot of concrete element for Model C

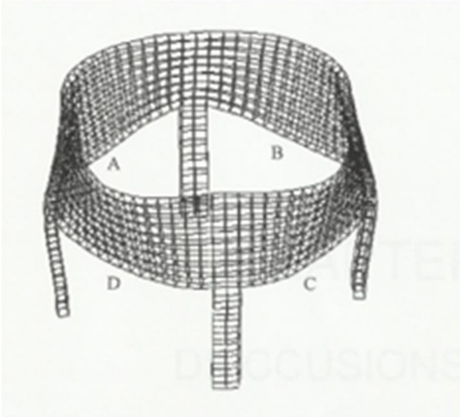

Figure 4.24 Deformed shape for Model C at ultimate load

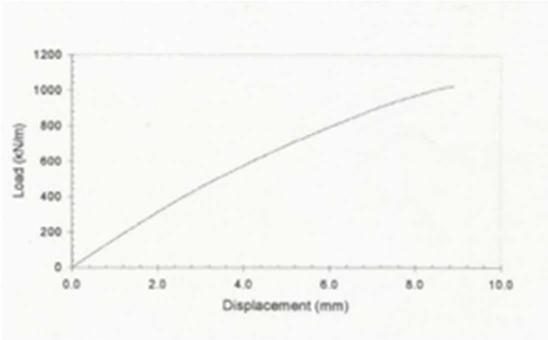

Figure 4.25 Load versus deflection mid-span at A,B,C and D

5.0 Summary of NLFEA Results

The NLFEA results of control models are acceptable, thus the same material properties of concrete and reinforcing steels, type of finite elements and the force control technique are assumed suitable to be used in ring beams models. The principal stress contour and vector plot for concrete element is use indicate the cracking and crushing location in the model. The normal stress contour plot for reinforcing steels can be present the yielding failure on reinforcement. With combination of these results, the failure mode for ring beams can be predicted. A single variable of tension stiffening is influencing the results of NLFEA for all models that involved tension reinforcements, A slight change in geometry or material modeling will change the NLFEA results. Generally, tension stiffening the load capacity of reinforced structure, because it allow the tensile stress being transfer from concrete to tension reinforcements effectively**.**

6.0 Conclusion

Non Linear finite element analysis (NLFEA) results of three ring beams models subjected to uniform distributed load indicate that failure mode of reinforced concrete ring beams are dependent on the geometry of the structure as shown in table 6.1. Generally, the show ring beams is fail in flexure, while the deep ring beams is fail in shear as happening on the straight reinforced concrete beams.

Table 6.1 Summary of ring beams failure mode at its span/depth ratio

Ring beam model	Span/depth ratio	Failure mode
Model A	8.56	Flexural
Model B	4.49	Flexural
Model C	2.3	Shear, Torsional

The extreme strain softening characters crack formation or tension stiffening parameter for concrete may highly influence the NLFEA results of control Model 3 and three ring beams models. From the NLFEA results for ring beams models. The range of tension stiffening from 0.002 to 0.003 is suitable to be used in NLFEA of ring beams.

7.0 Recommendation for future Research

Preliminary non-linear finite element analysis for reinforced concrete ring beams has been carried out in this paper, only a few parameters have been considered. The purposed for future research on NLFEA for concrete ring beams as below:

1-The laboratory experiment for shallow or deep reinforced concrete ring beams can present their actual behaviours and modes.

2-Different boundary condition and loading may be consider during the NLFEA of ring beams.

3-shell element and beam element can be used to model the concrete and reinforcing steel respectively and to compare the NLFEA results at different types of finite element.

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