International Journal of Engineering & Applied Sciences (IJEAS)
Vol.6, Issue 2(2014)1-12

DYNAMIC MAGNIFICATION FACTOR FOR CONCRETE WIDE BEAM UNDER FREE FALL LOADING

James H Haido

PhD, Faculty of Engineering, University of Duhok, Duhok, Iraq
E-mail address: *james.haido@uod.ac*

Abstract

Present endeavor is devoted to investigate the dynamic magnification factor of concrete wide beams contain different sizes of steel fibers under the effect of impact forces. Many parameters were considered in the current work namely central wide beam deformation, length of the used steel fibers and failure modes of the wide beams. Twenty two wide beams have been used to perform current impact test. A finite element model has been constructed with considering 3D solid elements to simulate the performance of the wide beam. It is observed that the computed dynamic magnification factor of the beam is decreased with introducing long steel fibers in the concrete wide beam member. Good matching with correlation more than 80% has been found between present finite element modeling results and the experimental outcomes with using four-noded solid elements in the analysis.

Keywords: dynamic magnification factor, free fall objects, concrete wide beam, three-dimensional finite element

1. Introduction

Wide beam is characterized by the width which is approximately equivalent to the twice of full depth [1-3]. Nowadays, this concrete member is widely used in many structural works for aesthetical aspects as multi-story building, bridges etc. According to many concrete construction codes, the flexural failure type is recommended rather than the shear failure mode as in the case of the wide beams.

Based on the collision phenomenon of the objects, they are separated into two categories namely rigid bodies (projectiles as usual) and deformable bodies (targets or structures) [4]. Due to the fact that the concrete is a brittle material, it is suffered from its weak strength to tension and impact actions with high rates [5-9]. To overcome this shortcoming, steel fibers may be introduced. The performance of the concrete beams under static transverse loadings have been studied extensively and it was concluded that the steel fibers have a great role in improving the beam strength [10-15]. Regarding the dynamic forces, their identification is important for structural response estimation, structural design optimization and control the vibration for structures. Due to the using of the reinforced concrete material in many civil and military engineering constructions, the possibility of exposing them to the dynamic forces such as impact and blast loads is increased. Impact force is a transient loading produces structural fatigue with dependence on the impact position and its time history [16, 17], while blast loadings are intensive dynamic forces produced by detonations with short duration [18]. With respect to the dynamic behavior of structures, the dynamic magnification factor of the concrete wide beam reinforced with steel fibers has not been widely considered so far. Thus, further investigations in this direction are considered essential with taking into account the effect of the used fiber length.

To assess the dynamic performance of the structure, the impact strength and consequently the dynamic magnification factor are regarded as important factors to be determined [19]. Present research comprises of two parts that are experimental and theoretical sections. The first part includes the measuring of the wide beam impact strength in terms of the dynamic magnification factor. Theoretical section contains the implementation of the nonlinear solid finite element modeling for the impact test in ANSYS simulation program and comparing the outcomes with the present experimental data.

2. Experimental Program

A fresh concrete mix with weight proportions of 1 Portland cement:1.5 fine aggregate (sand):2.5 coarse aggregate (gravel):0.5 tap water has been used in the preparation of the wide beam samples. Two shapes of steel fibers with different length were employed in reinforcing present wide beams namely corrugated and hooked ends steel fibers with 2 cm and 4 cm in length and have a constant cross sectional area of 0.785 mm^2. The selected fiber contents in present wide beams are 10 and 20 kg per one cubic meter of concrete. The properties of the concrete components, hardened concrete and steel fibers are given in Table 1. Twenty two wide beam specimens (Figure 1) have been cast with using aforementioned concrete mix and different steel fiber contents as listed in Table 2. Two specimens have been adopted per each fiber content and the average value of the resulted parameters was determined and used in the present investigation. The compressive strength of each hardened concrete sample has been measured with using standard concrete cubes with size of 150 mm after 28 days of water curing according to the Iraqi standards [20]. Impact test has been conducted by applying the free fall force on the clamped (fixed) wide beam as depicted in Figure 2. The schematic diagram of the test is illustrated in Figure 3. Wide beam is loaded by a single point impact load located at the top center of the beam surface. The dynamic magnification factor have been calculated at the first cracking case, diagonal cracking failure and collapse failure (Figure 4) of the wide beam. The first cracking case refers to the appearance of the first flexural cracking on the beam. The diagonal cracking is the first inclined crack started from the support due to the shear effect while the collapse represents the beam separation into two or more pieces under the effect of falling weight. The impact force produced from the falling of steel ball on the top surface of the wide beam is calculated as a product of the striker (ball) weight and the dynamic magnification factor. Present dynamic magnification factor D_{factor} has been determined by depending on the potential energy conversion [21] to kinetic energy as follows [22]:

$$D_{factor} = 1 + \sqrt{1 + \frac{2H_d F_d}{D_{static}}} \qquad (2)$$

where

H_d = Dropping distance measured from the bottom of the ball to the top surface of the beam

$$F_d = \frac{1 + \frac{13\,beam\ mass}{35\,ball\ mass}}{\left(1 + \frac{beam\ mass}{2\,ball\ mass}\right)^2} \qquad (3)$$

D_{static} = static central deflection of the beam = $\frac{ball\ mass \times g}{K}$ (4)

$$K = 48EI/L^3 = \text{Beam Stiffness} \quad [23] \tag{5}$$

$$E = 4700\sqrt{Fc'} = \text{concrete modulus of elasticity} \tag{6}$$

I = moment of inertia of the beam
L = span of the beam
g = gravitational acceleration
Fc' = concrete compressive strength

Table 1: Characteristics of the steel fibrous concrete material

Item	Property
Cement	Specific gravity = 3.15
Sand	fineness modulus = 2.5
Gravel	Bulk density = 2600 kg/m^3
Steel fibers	Tensile strength = 950 N/mm^2
B1 concrete	Compressive strength = 29.5 N/mm^2
B2 concrete	Compressive strength = 29.6 N/mm^2
B3 concrete	Compressive strength = 29.6 N/mm^2
B4 concrete	Compressive strength = 29.5 N/mm^2
B5 concrete	Compressive strength = 29.4 N/mm^2
B6 concrete	Compressive strength = 30.1 N/mm^2
B7 concrete	Compressive strength = 30.0 N/mm^2
B8 concrete	Compressive strength = 30.8 N/mm^2
B9 concrete	Compressive strength = 30.6 N/mm^2
B10 concrete	Compressive strength = 31.0 N/mm^2
B11 concrete	Compressive strength = 33.0 N/mm^2

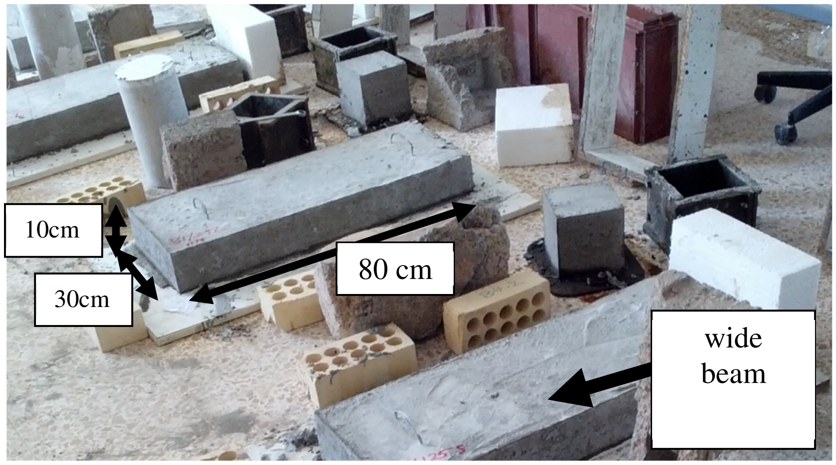


Figure 1: Wide beam samples and concrete cubes

Table 2: Steel fiber contents for concrete wide beams

Wide beam designation	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11
Content of steel fibers (kg/m^3)	No fiber (plain concrete)	10	10	10	10	10	20	20	20	20	20
Content of 4cm steel fibers (kg/m^3)*	No fiber (plain concrete)	0	3	5	7	10	0	6	10	14	20
Content of 2cm steel fibers (kg/m^3)*	No fiber (plain concrete)	10	7	5	3	0	20	14	10	6	0

Figure 2: Present impact test for wide beam

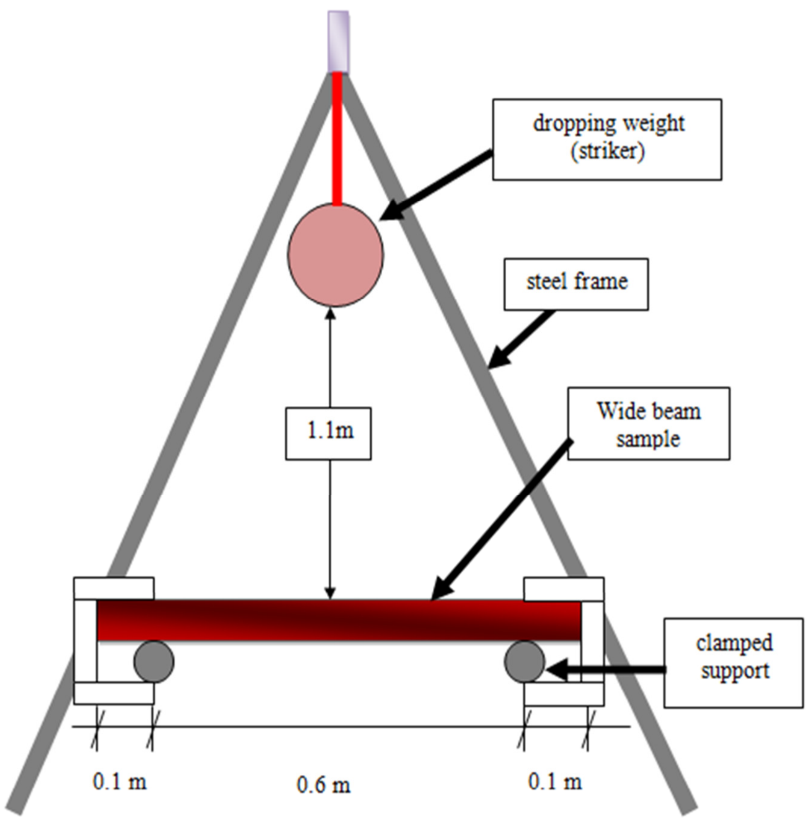


Figure 3: Layout of the falling weight test for wide bam

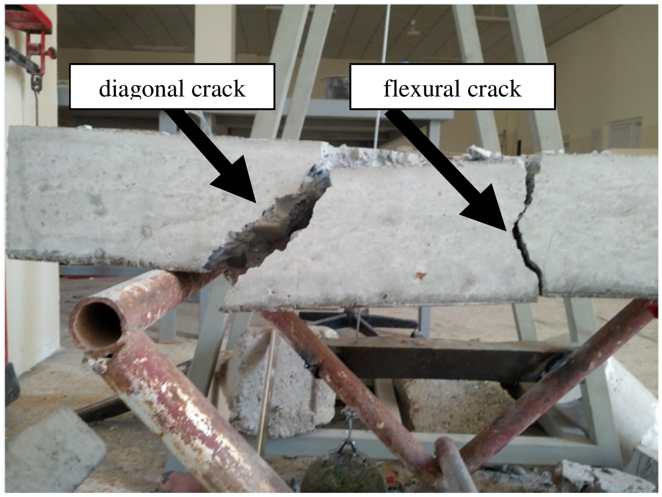


Figure 4: Failure of the wide beam under impact action

3. Numerical Simulation

A simulation (Figure 5) has been performed in ANSYS workbench 14 finite element program for present impact experiment. The striker (steel ball) was modeled with using four-noded solid elements (Figure 6a) and the wide beam is simulated with the eight-noded hexagonal solid elements (Figure 6b) as well as four noded quadrilateral solid elements. Nonlinear analysis has been adopted in the present ANSYS finite element analysis of wide beam.

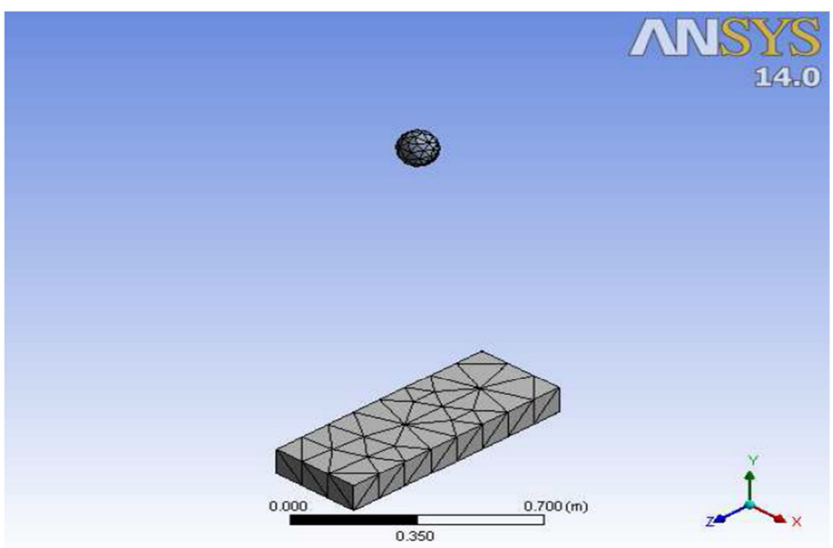
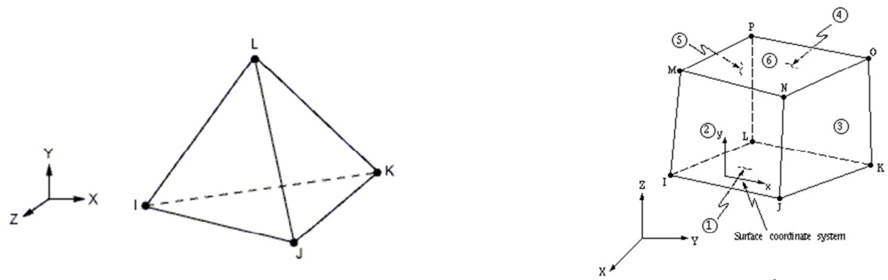


Figure 5: Finite element model of the impact test



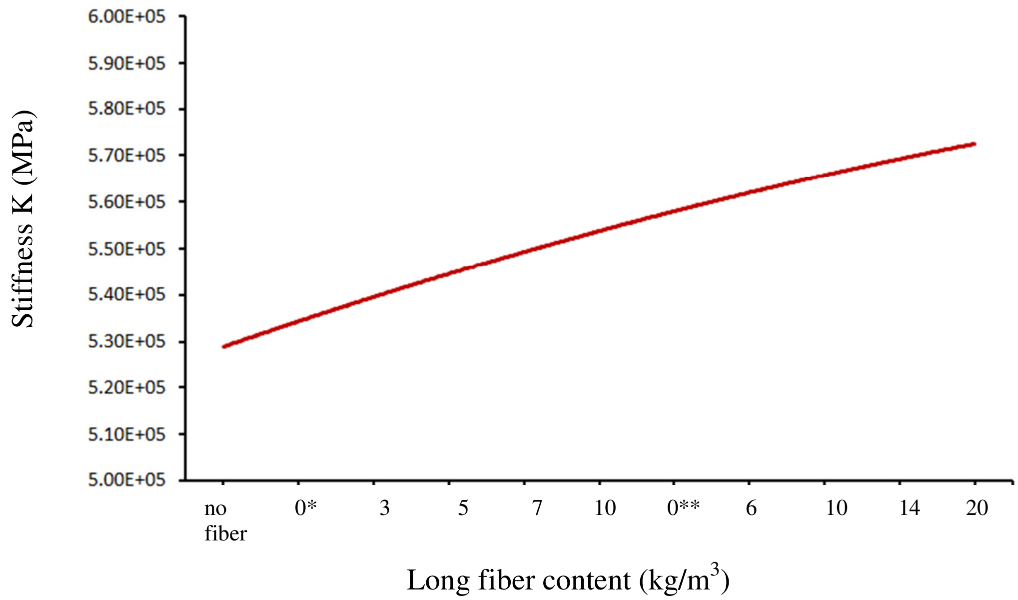
a b

Figure 6: Solid elements [24]

4. Experimental and Analytical Outcomes

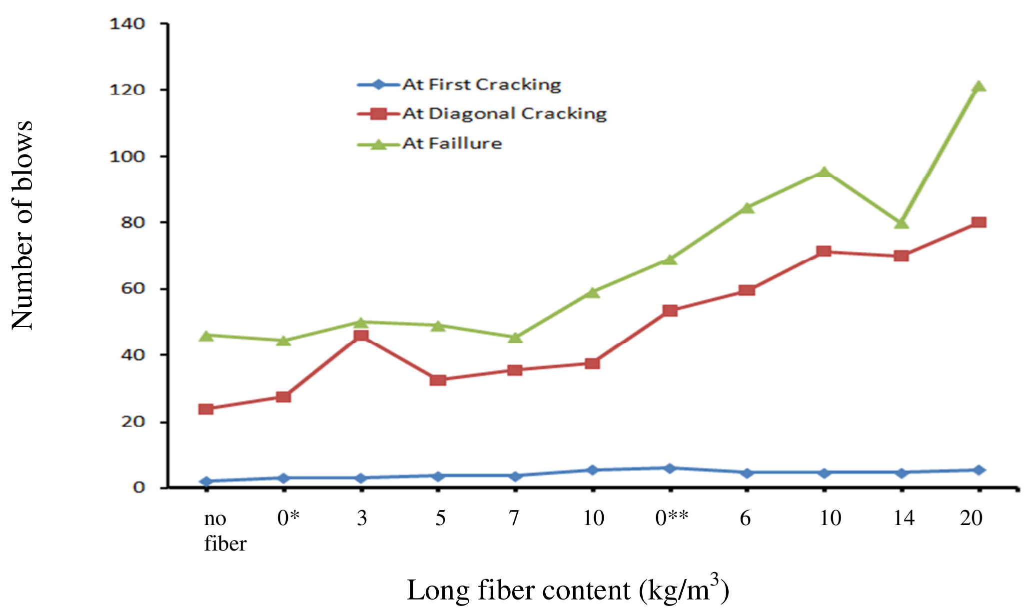
Stiffness value has been determined for each beam depending on the Eq. 5 as depicted in Figure 7. It is demonstrated that the stiffness of the beam is improved with introducing long fibers in the concrete by more than 4% compared to beam reinforced with short fibers.

In order to find the dynamic magnification factor, it is required to estimate the static deformation of the wide beam under the falling weight as aforementioned before. The static deflection of the wide beam has been calculated as a product of the static deflection produced from a single strike and the number of blows (Figure 8) for the striker (ball) as illustrated in Figure 9. The total static deflection has been determined at three failure cases of the beam namely first cracking, diagonal cracking and collapse cases. According to the Figure 9, it is observed that the maximum deflection of the wide beam is increased with the using of long steel fibers. The dynamic magnification factor has been computed in complying with the Eq. 2 and its value compared with the ANSYS numerical analysis outputs as illustrated in Figures 10-12. A reduction in the dynamic magnification factor has been observed with increasing the dosage of long steel fibers in the concrete that led to increase the dynamic ductility (area under load-deflection curve) of concrete. Good matching can be obtained between present experimental and finite element modeling with using of four-noded solid elements in the simulation of concrete wide beam. An overestimation is observed in the dynamic magnification factor by using hexagonal elements in the analysis of wide beam especially with increasing the fiber content as in the case of beams B7-B11.



* fiber content is 10 kg/m^3
** fiber content is 20 kg/m^3

Figure 7: Flexural stiffness of the wide beams



* fiber content is 10 kg/m^3
** fiber content is 20 kg/m^3

Figure 8: Number of striker blows required for beam failure cases

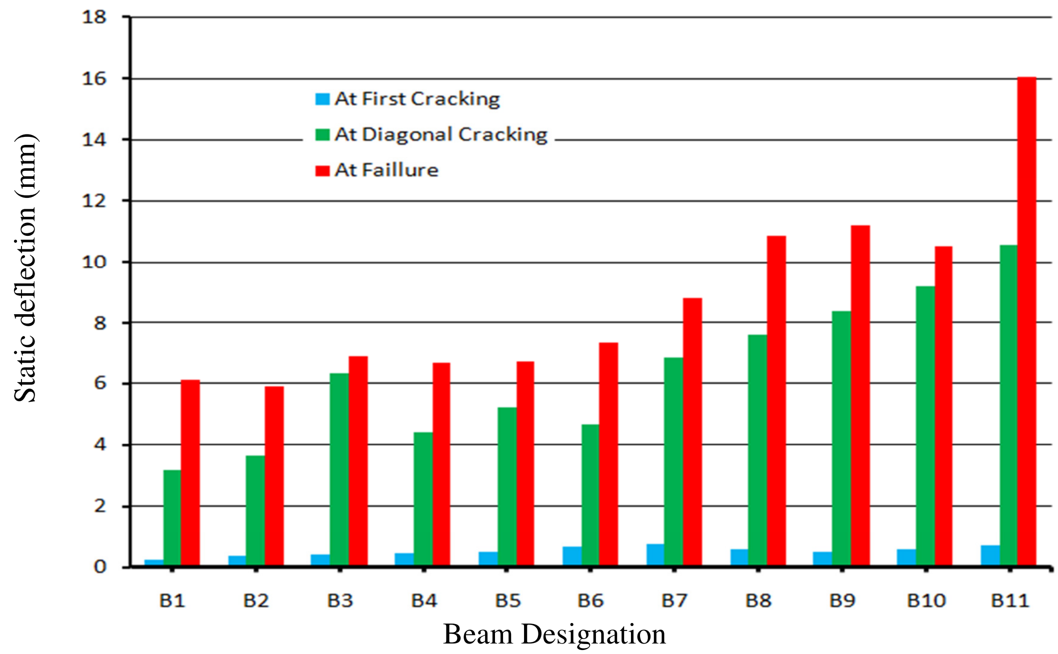


Figure 9: Flexural stiffness of the wide beams

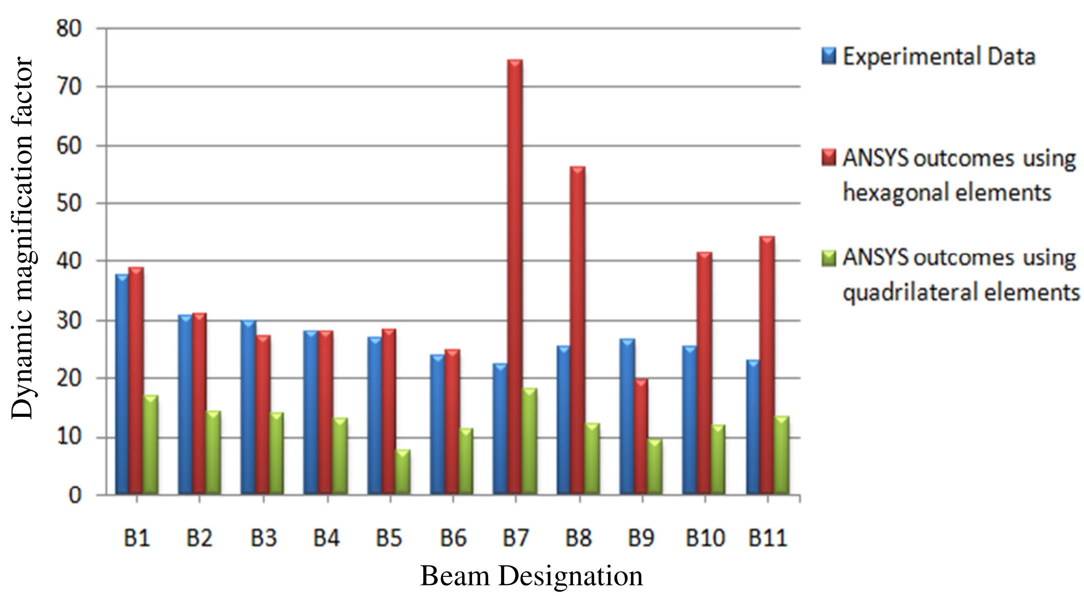


Figure 10: Dynamic magnification factor at first cracking of wide beam

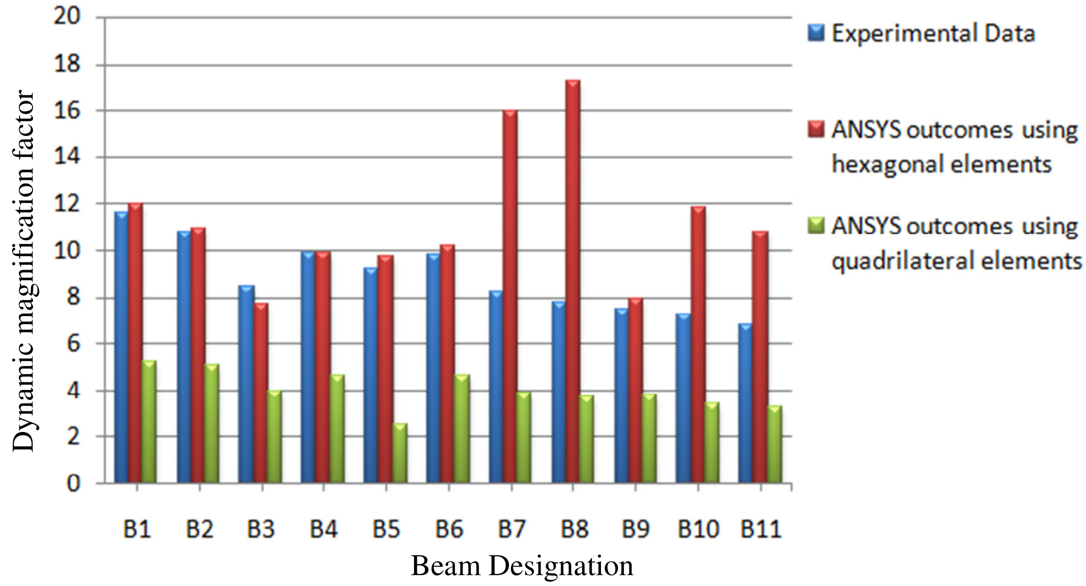


Figure 11: Dynamic magnification factor at diagonal cracking of wide beam

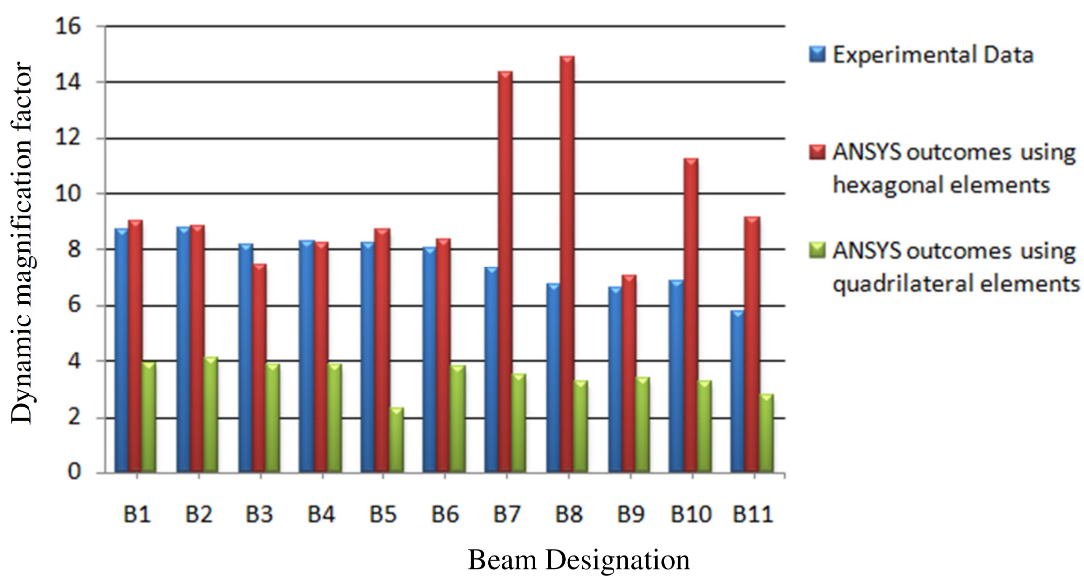


Figure 12: Dynamic magnification factor at collapse failure stage of wide beam

5. Conclusions

Impact test has been conducted for many concrete wide beams reinforced with steel fibers. The effect of steel fiber length on the dynamic performance of the wide beam has be investigated in terms of dynamic magnification factor. Based on the outcomes of the present endeavor, conclusions have been drawn as hereunder:

1- Wide beam behavior is improved with increasing the length of the used steel fibers.

2- The dynamic magnification factor of steel fiber reinforced concrete wide beam is influenced by steel fibers length. This factor is decreased with a percentage of 12.83% by using long fibers for reinforcing concrete wide beam.

3- The using of four-noded solid elements in the modeling of wide beam performance gives good correlation with the experimental data.

4- With increasing the dosage of steel fibers, the dynamic magnification factor increases by employing hexagonal elements in the simulation of wide beam behavior.

Acknowledgments

The authors are very thankful to the Faculty of Engineering, University of Duhok for the finical grant of present study. The authors want to thank Professor Jowhar Rasheed Muhammed, head of the water resources engineering department at the Faculty of Engineering for his assistance.

References

[1] American Concrete Institute ACI committee-318 Code, *Requirements for structural concrete and commentary*, 1971.
[2] American Concrete Institute ACI committee-318 Code, *Requirements for structural concrete and commentary*, 2005.
[3] Prota, A., Tan, K.Y., Nanni, A., Pecce, M., Manfredi, G., Performance of shallow reinforced concrete beams with externally bonded steel-reinforced polymer. *ACI Structural Journal*, 103(2), 163-170, 2006.
[4] Ozbolt, J., Sharma, A., Numerical simulation of reinforced concrete beams with different shear reinforcements under dynamic impact loads. *International Journal of Impact Engineering*, 38, 940-950, 2011.
[5] Brandon, D.G., Dynamic loading and fracture, Blazynski TZ, editor. *Materials at high strain rates. Elsevier*, 187-218. 1987
[6] Ozbolt, J., Rah, K.K., Mestrovic, D., Influence of loading rate on concrete cone failure. *International Journal of Fracture*, 139, 239-252, 2006.
[7] Ozbolt, J., Sharma, A., Reinhardt, H.W., Dynamic fracture of concrete compact tension specimen. *International Journal of Solids and Structures*, 48, 1534-1543, 2011.
[8] Saatci, S., Vecchio, J.V., Effect of shear mechanisms on impact behavior of reinforced concrete beams. *ACI Structural Journal*, 106(1), 78-86, 2009.
[9] Travas, V., Ozbolt, J., Kozar, I., Failure of plain concrete beam at impact load: 3D finite element analysis. *International Journal of Fracture*, 160, 31-41, 2009.
[10] ACI Committee 544, State of the art report on fiber reinforced concrete, *Fiber reinforced concrete int., symposium*. Detroit: ACI Publication, SP-81, 1984.

[11] Hsu, L.S., Hsu, C.T.T., Stress-strain behavior of steel-fiber high-strength concrete under compression. *ACI Structural Journal*, 91(4), 448–457, 1994.
[12] Abdul-Razzak, A.A., Mohammed Ali, A.A., Modelling and numerical simulation of high strength fibre reinforced concrete corbels. *Applied Mathematical Modeling Journal*, 35(6), 2901–2915, 2011.
[13] Abdul-Razzak, A.A., Mohammed Ali, A.A., Influence of cracked concrete models on the nonlinear analysis of high strength steel fibre reinforced concrete corbels. *Composite Structures*, 93, 2277–2287, 2011.
[14] Haido, J.H, Prediction of static behavior for SFRC deep beams using new and simple nonlinear models, *Caspian Journal of Applied Sciences Research*, 1(5), 1-26, 2012.
[15] Haido, J.H., Investigation of SFRC corbel performance using a developed nine-noded lagrangian elements. *ARPN Journal of Engineering and Applied Sciences*, 7(8), 963-970, 2012.
[16] Khoo S.Y., Ismail Z., Kong K.K., Ong Z.C., Noroozi S., Chong W.T., Rahman A.G.A., Impact force identification with pseudo-inverse method on a lightweight structure for under-determined, even-determined and over-determined cases. *International Journal of Impact Engineering*, 63, 52-62, 2014.
[17] Liu, J., Han, X., *Computational inverse procedure for identification of structural dynamic loads computational mechanics*, Heidelberg: Springer Berlin; 2009. p. 323.
[18] Zhao, C.F., Chen, J.Y., Damage mechanism and mode of square reinforced concrete slab subjected to blast loading. Theoretical and Applied Fracture Mechanics, 63–64, 54–62, 2013.
[19] Liu, F., Chen, G., Li, L., Guo, Y., Study of impact performance of rubber reinforced concrete. *Construction and Building Materials*, 36, 604–616, 2012.
[20] Building Research Center-Scientific Research Council of Iraq, *Iraqi building code requirements for reinforced concrete, Code 1*, 1987.
[21] Rao, H.S., Ghorpade, V.G., Ramana, N.V,, Gnaneswar, K., Response of SIFCON two-way slabs under impact loading. *International Journal of Impact Engineering*, 37, 452–458, 2010.
[22] Akin, J. E., *Impact load factors*. https://www.clear.rice.edu/mech403/HelpFiles/ImpactLoadFactors.pdf, 2013.
[23] Karnovsky, I.A., Lebed, O, *Advanced Methods of Structural Analysis*, Springer Science+Business Media, LLC, 2010.
[24] ANSYS, Inc., *Element reference*, SAS IP, Inc., 2009.