

Reinforced Concrete Spandrel -Floor Beams Interaction

Rasha M.Shareef Salman¹, Anis A.Mohamad Ali²

Ph.D. Student, Department of Civil Engineering, Engineering College, University of Basrah, Iraq¹

Professor, Department of Civil Engineering, Engineering College, University of Basrah, Iraq²

ABSTRACT: This paper is aimed to study the effects of the floor beam on the strength and the behaviour of the solid and hollow spandrel beams. ANSYS14.0 software program has been used to simulate the 3-dimension finite element model of reinforced concrete rectangular spandrel-floor beams from available experimental data. Verification has been achieved by comparing the analytical results using the ANSYS14.0 with the corresponding experimental results to ensure the confidence and the reliability of the F.E. models. Specific analysis factors have been adopted that give more compatible results. Then, flanged floor beam sections are simulated with different flange width and depth to investigate the response of the spandrel beam behaviour. Some debates and design recommendation are provided.

KEYWORDS: spandrel beams, hollow sections, torsion, flanged floor beam, ANSYS14.0.

I. INTRODUCTION

The floor-spandrel beam assembly is an important and critical part of any frame structure. The interaction between the floor and the spandrel beam makes the situation more complicated and quite different. In actual structure, the spandrel beams are often placed at the external edge and supporting the floor beam that attached to the slab to transfer the load from the slab into the columns. Fig. 1 shows some types of spandrel beams. Such assembly gives a notation that the spandrel beams subjected to a complex stresses distribution due to the effect of the multi-directional forces such as axial forces, torsion, bending moment and shear. This paper is aimed to study the effect of the flanged and rectangular floor beams on the spandrel beams behaviour.

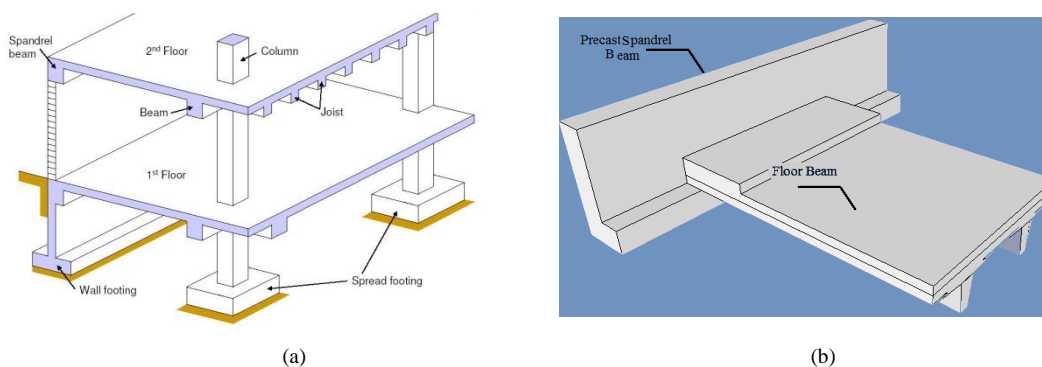


FIG.1 Some Typical Spandrel Beams (a) Spandrel beam as a part of the structure (b) Precast spandrel beam

II. LITERATURE SURVEY

Many experimental works were achieved to study the behaviour of spandrel beams under various type of loading system^[2]. Three main loading cases can be classified as:

1. A spandrel beams loaded by a floor beam (Collins and Lampert 1973,Hsu and Burton, Hsu and Hwang 1977, Abul Mansur and Rangan 1978), as shown in Fig. (2-a).
2. Floor system with spandrel beams (Bishar and Londot 1979), as shown in Fig. (2-b).
3. A spandrel beam in frames subjected to lateral loading (Pantazopoulou and Moehle 1990), as shown in Fig. (2-c).

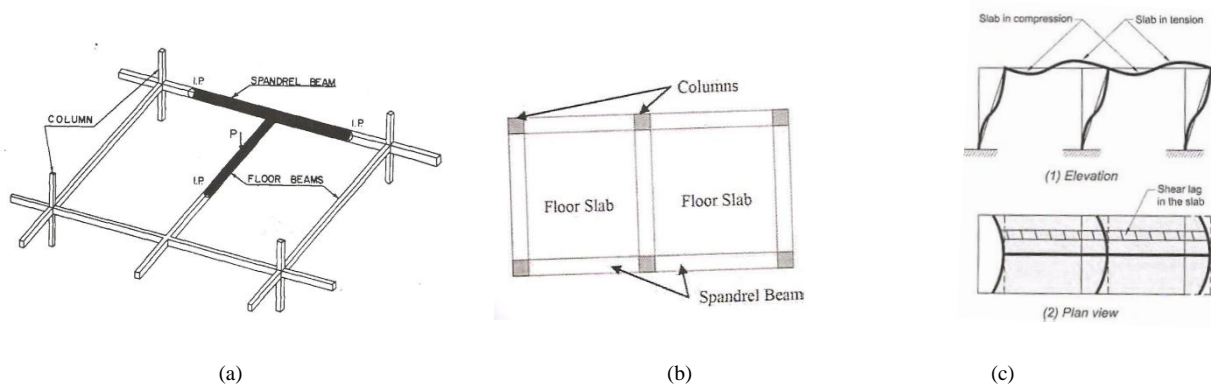


Fig. 2: Loading Systems on Spandrel Beams (a) Spandrel beam under concentrated load (Hsu and Burton 1974) (b) Floor system with spandrel beams (Bishar and Londot 1979) (c) spandrel beams under lateral beams (Pantazopoulou and Moehle 1990).

In 1973, Collins and Lampert^[3] tested six spandrel beams specimens with a concentrated load applied at midspan of the floor beam. It was found that these specimens designed assuming the members had zero torsional stiffness behaved as satisfactorily as specimens designed assuming uncracked stiffness values. They concluded that the ratio of torsional to flexural stiffness will drop at cracking and that will cause redistribution of the torsion and flexural moments. So that the magnitude of compatibility torsion is over estimate if gross stiffness is used. Also, they concluded that for the compatibility torsion, design should be for a twist and not for a torque and the torsional reinforcement is to distribute the cracks caused by twist. The design procedures could be simplified, if zero torsional stiffness is assumed and only minimum torsional reinforcement is required in order to ensure the ductility and the limit crack width.

Hsu and Burton^[10], 1974, tested ten specimens classified in to two series (A and B) according to type of loading. Series A concentrated load at the midspan of the floor beam. Series B uniform loads on the floor beam simulated by four concentrated loads. It was concluded that using the limit design concept is both feasible and desirable to obtain the torsional stress. Minimum steel ratio in the floor beam at the joint may be taken as 0.45% for crack control.

Mohamed Ali^[9], 1983 studied experimentally the behaviour of the spandrel beam and proposed equations to determine the torsional resistance prior and after cracking. He concluded that longitudinal steel of spandrel beams are not significantly effective in resisting torsion. He mentioned that the spandrel beams should not designed from a strength consideration only but also by limiting the angle of twist.

Jawad^[60], 1988 suggested expressions to calculate the torsional strength, twisting angle and the torsional stiffness of the spandrel beams. In this study, the case of spandrel beams loaded by floor beams are adopted in order to study the effect of the floor properties on the strength and behaviour of the spandrel beam. Sixteen experimental specimens were simulated using ANSYS14.0 software. A three-dimensional reinforced concrete spandrel members were established using F.E method. Comparison between numerical results and available experimental data has been achieved to validate the numerical models.

III. FINITE ELEMENT SIMULATION AND MATERIAL MODELING USING ANSYS14.0

The finite element analysis is a reliable and usable means for analysing of civil structures with the availability of concrete technology. It is an approximate numerical method that can make a realistic representation of reinforced concrete and take into account the actual complexity of the construction. The behaviour of reinforced concrete member

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can be described by load-deflection relationship which is linear until cracks occur that cause a nonlinear response. Using the finite element method in nonlinear structural problems results in a system of nonlinear equations as:

$$\{f\}_e = [K]_e \cdot \{a\}_e \quad \text{Eq.(1)}$$

$$[K] = \sum_n \int_v [B]^T [D] [B] dv$$

Where $[K]$ is the element stiffness matrix expressed as. In the present study, the three dimensional brick isotropic element, solid 65, was selected to represent the concrete. This element is capable of cracking in tension and crushing in compression, hence, compressive and tensile strength of the experimental specimens should be identified. The presence of the crack at the integration point is represented by modification of the stress –strain multilinear relation of the nonlinear concrete material. Suitable shear transfer coefficients should be selected for open and closed cracks range between 0.0 to 1.0. In the present analysis, the coefficient values of 0.5 and 0.9 were selected which provided more accurate analysis results. If the material at an integration point fails in uniaxial, biaxial or triaxial compression, the material is assumed to be crushed at that point. Longitudinal and stirrups steel of different size and properties are represented using link180 with bilinear stress-strain relationship.

Soild185 element, was used for representing the steel lever arms with linear response. These arms were used to provide torsional fixity at the ends of spandrel beams of the experimental members. The materials of experimental members discretised correctly by modelling the geometry of the spandrel-floor beams as it is given in physical reality, and apply material parameters which are easily accessible and understandable to an engineer Fig. (3-a) shows a typical finite element model of the experimental specimens. Meshing geometry of the full scale tested beams was applied to a desirable number of elements. Convergence study towards validating adequacy of the adopted discretization is performed, by doubling the number of elements and comparing results, until the difference in results is insignificant and no further refinement is necessary. Fig. (3-b) shows the meshing of a typical finite element model. Simulate of longitudinal and stirrup steel bars for spandrel and floor beams individually according to their actual location and properties in the experimental beams as shown if Fig. (3-c).

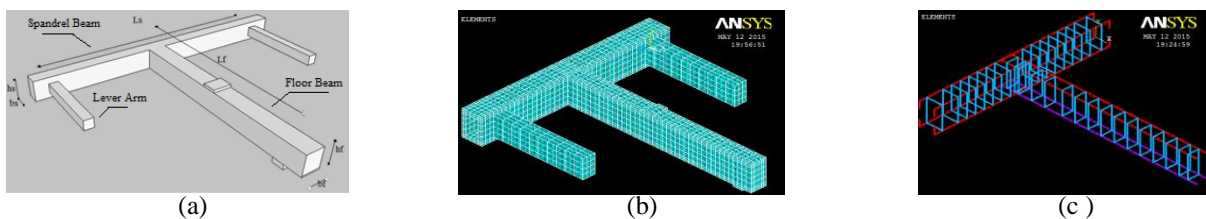


Fig.3:F.E Simulation ; (a) Typical finite element model, (b) Meshing concrete model, (c) Longitudinal and stirrups steel simulation

IV. ANALYSIS RESULTS

The dimensions and concrete properties of the experimental beams are listed in table(1). Test results are used for the verification of the numerical models. It can be concluded that the analysis results of the ultimate load capacities, ultimate torque, and angle of twist of the numerical models were closer to the experimental results as shown in table (1).

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Table (1) Specimens Details and Analysis Results

Investigator	Spec	Spandrel beam			Floor beam			f'_c MPa	E_c GPa	Ultimate load (kN)		Pan Pex	Ultimate Torque (kN.m)		Tans Texp	Angle of Twist (Rad/m) $\times 10^{-3}$		Θ_{an} Θ_{ex}
		Ls M	bs mm	hs mm	Lf m	bf mm	hf mm			Pex	Pan		Tex	Tan		Θ_e	Θ_a	
Jawad ^[6] GR-	B2 [†]	1.2	120	300	1.6	120	180	32.9	30.8	84.3	85.0	1.00	2.18	2.60	1.19	20	10.0	0.50
	C2 [†]	1.2	120	300	1.6	120	180	31.4	30.2	73.5	74.0	1.00	3.38	2.94	0.87	25	17.0	0.68
	D2 [†]	1.2	120	300	1.6	120	180	33.3	31.5	95.6	112	1.17	3.40	3.00	0.88	15	14.8	0.99
	B4 [†]	1.8	120	300	1.8	120	180	32.9	3.29	69.5	70.0	1.00	3.56	2.90	0.81	33	22.0	0.67
	C4 [†]	1.8	120	300	1.8	120	180	29.9	28.9	74.4	76.0	1.02	5.30	3.80	0.72	42	31	0.73
	D4 [†]	1.2	120	300	1.6	120	180	43.6	34.7	70.7	69.0	0.98	3.37	3.50	1.03	20	14.5	0.73
	E2 [†]	1.2	120	300	1.6	120	180	29.3	28.9	83.0	85.0	1.02	3.45	3.9	1.13	18	17	0.94
	E3 [†]	1.8	120	300	1.8	120	180	30.2	29.6	98.0	98.0	1.00	2.9	3.2	1.10	12	9.0	0.75
Muherdeen ^[7] GR-	A2 [†]	1.5	120	300	1.5	120	300	30.3	29.6	95.2	79.7	0.84	1.80	1.92	1.06	10	4.2	0.42
Easa ^[8] GR-	D1 ^{††}	1.5	200	300	1.7	150	300	24.6	25.1	110	113	1.02	6.18	6.33	1.02	26	22.8	0.88
	D2 ^{††}	1.5	200	300	1.7	150	300	26.1	24.3	110	113	1.02	5.45	5.5	1.00	34	33.5	0.98
	D4 ^{††}	1.5	200	300	1.7	150	300	24.7	24.5	110	112	1.01	5.45	3.90	0.72	34	21.0	0.62
	C1 ^{††}	1.5	200	300	1.7	150	300	28.5	28.1	120	96	0.80	9.08	8.58	0.94	33	26.0	0.79
	C2 ^{††}	1.5	200	300	1.7	150	300	26.7	27.6	110	110	1.00	6.13	5.32	0.87	34	32.0	0.94
Abul Mansur and Rangan ^[4]	SA3 [†]	3.0	180	300	3.0	180	300	40.2	-	138	138	1.00	6.6	5.4	0.82	14	11.2	0.80
Mohamad Ali ^[4]	GR3 [†] -A1	0.8	75	200	0.8	75	200	30	30.0	70	74.4	1.06	1.7	1.6	0.94	6.5	4.8	0.74

[†]Solid Section

^{††}Hollow Spandrel Section

V. EFFECT OF POSTIVE STEEL RATIOS OF FLOOR BEAM

Six different values of steel ratios (0.00295, 0.015, 0.018, 0.021, 0.024 and 0.026) were suggested for the positive longitudinal bars of the floor beam to investigate the system response to the floor beam reinforcement. The details and properties of materials are the same as GRC3^[6]. Total load was divided equally on nodes of the steel plate at the mid span of the floor beams. Adopted maximum effective width of the flanged sections were not exceeding the maximum value that recommended in ACI318-08, section 8.12.1.

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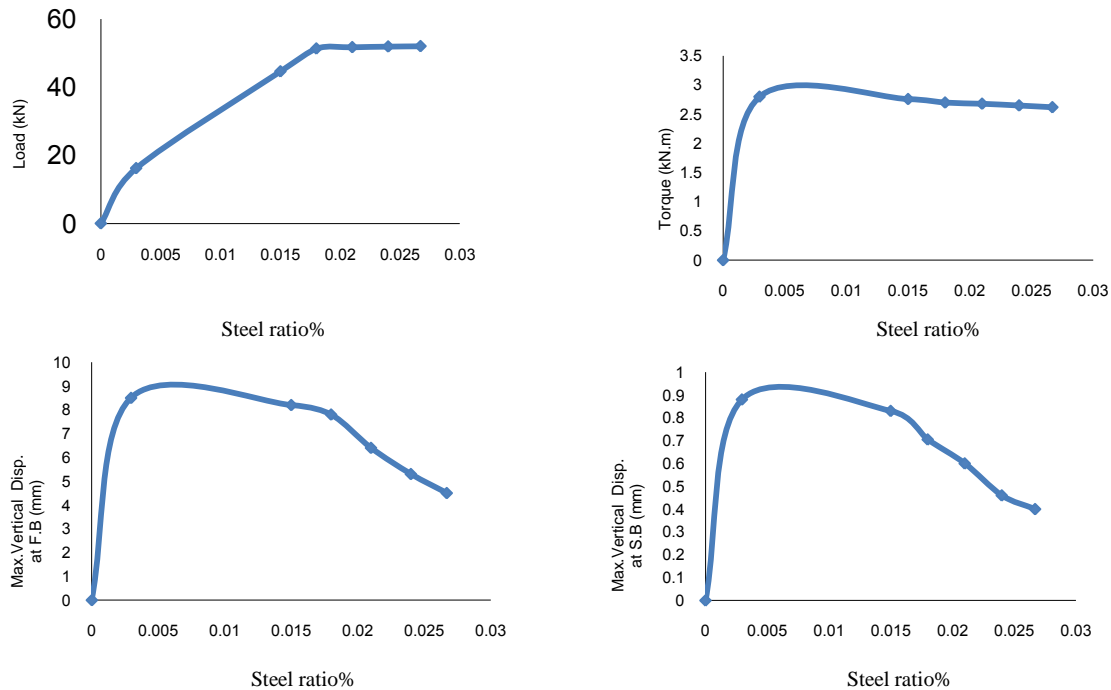


Fig.4 Effects of positive steel ratio on floor beams on the ultimate load, torque, maximum displacements at the mid spans of the floor and spandrel beams respectively.

As shown in Fig. (4), it can be noticed that ultimate load increase rapidly until it nearly reaches the maximum steel ratio ($e_{max}=0.0017904$) after that slightly changes can be noticed, while the analytical torques were reduced after a minimum steel ratio ($e_{min}=0.00295$). Spandrel and floor beams deflections were reduced as the steel ratios increase due to stiffening of the floor member.

VI. EFFECTS OF FLOOR BEAM SECTIONS

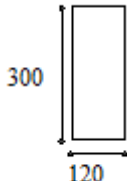
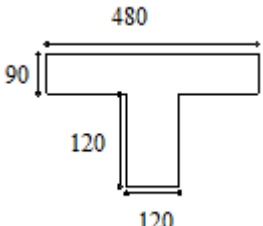
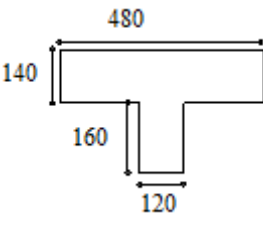
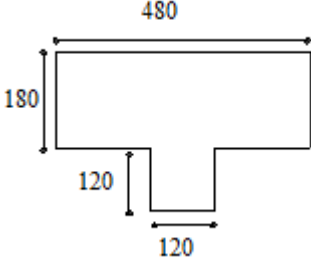
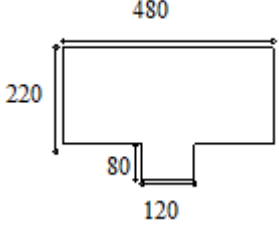
In this case study, a comparison was made between the analytical results of the rectangular and those of flanged sections. All sections have the same material properties and loading type. Table (2) shows the values of ultimate load, ultimate torque, maximum floor deflection and maximum spandrel beam deflections of different floor beam sections. Four values of effective flange depth (90, 140, 180, 220) mm were adopted to study the effects of the flange sections on the overall behaviour of the spandrel-floor beams. As shown in table (2-a) and (2-b), the adopted effective flange width are 480mm and 300mm respectively.

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Table (2):Effect of floor beam sections
(a):Flanged width equal to 480mm

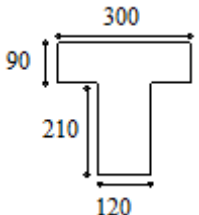
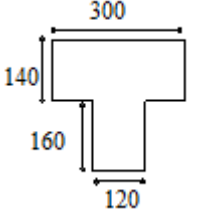
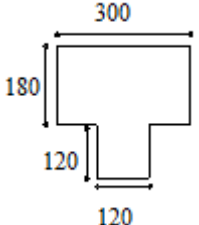
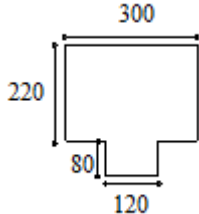
F.B Sections	Ultimate load (KN)	Ultimate Torque (kN.m)	Max. F.B Deflection(mm)	Max. S.B Deflection(mm)
	100	1.75	1.6	0.28
	110	2.48	6.84	0.29
	104.2	3.07	8.65	0.38
	92.5	3.47	10.88	0.39
	86.9	4.48	12.02	0.46

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(b): Flanged width equal to 300mm

	106.95	2.6	8.9	0.37
	85.8	2.968	11.4	0.46
	87.0	3.53	12.4	0.49
	82.76	3.30	9.70	0.41

It can be noticed that:

- Both the flanged width and the depth have significant effects on the overall system response.
- Models with effective width equal to 480 show more ultimate loads capacities than these of other sections.
- Flanged sections show more torque transferring than the rectangular sections.

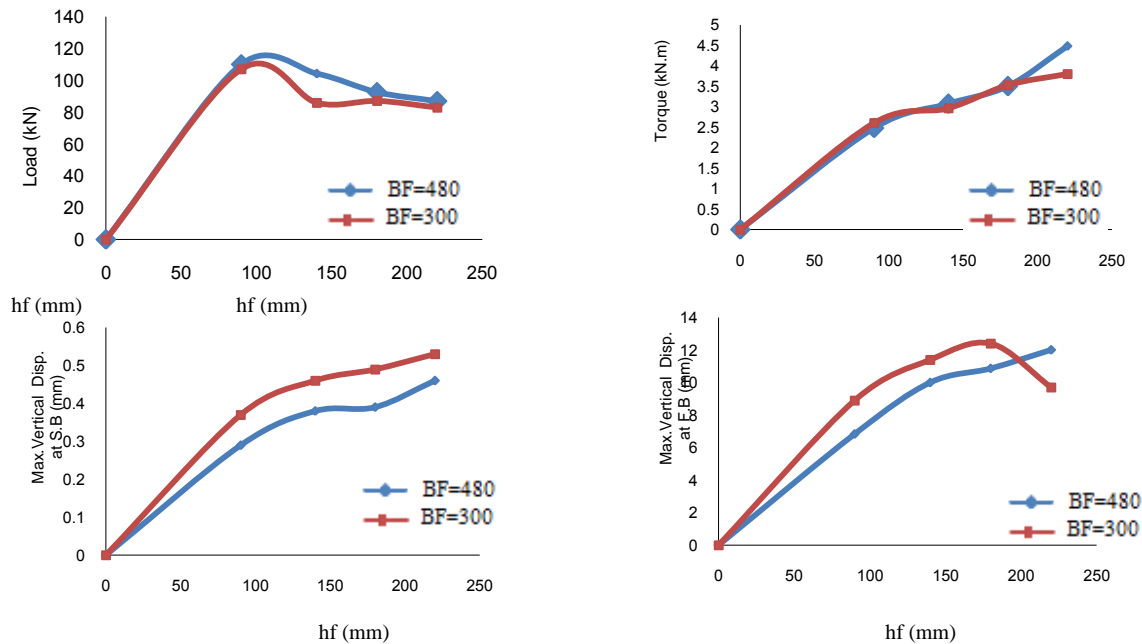


Fig. (5) shows the effects of the flange depth on the ultimate load, ultimate transfer torque, the maximum values of the mid span deflection of the spandrel and floor beams respectively.

Fig. (5) shows that: Increasing the flanged depth of the floor beams more than about 140mm will reduce the strength capacity. The maximum deflections at the mid span of the floor and spandrel beams will increase due to heavy dead weight.

VII. CONCLUSION

From the present study it can be concluded that:

- Longitudinal steel reinforcement bars of the floor beams have significant effects on the spandrel beam behaviour and response.
- The flanged floor beams are more stiff than the rectangular sections and that will increase the ultimate load capacities with more torque transferring .
- Adequate flange depth should be not greater than the half of the overall floor depth.
- The behaviour of the spandrel beams are widely monitored by the floor beam properties.

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