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Seismic Performance Assessment of Long Span SPC Composite Beam

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Abstract

Many research works on the steel plate-concrete structures have been conducted recently. The steel plate concrete structures as composite structures can be effectively used to replace conventionally reinforced concrete structures through reducing construction duration. In this research, a technical assessment of seismic performance for low rise building was suggested based on the ASCE-41 design guidelines. After the push-over analysis, the roof displacement was transformed to both Spectral Acceleration and Spectral Displacement for the targeted steel moment resisting frame. The mode shape and participation factors were calculated using the capacity spectrum method. The equivalent damping ratio and effective damping ratio were used to get the modified damping coefficient. A series of experimental test were conducted to evaluate the performance of the target object, modeling parameter, and acceptance criteria. The backbone curve from the experimental tests was used to input the parameters relating performance objection point. Additionally, three earthquakes such as El Centro, Northridge, and San Fernando were used to get the seismic responses, for the inelastic dynamic analyses.

The following results were acquired from the analytical and experimental results above. First, the story drift of the composite beams in the inelastic dynamic analysis was greater than other RC and Steel structures. Second, the performance levels for RC, Steel, and tested Composite beam were IO(immediate occupancy), LS(life safety), and also LS(life safety) levels, respectively. Third, the performance points could be properly estimated and evaluated if we appropriately adopt modeling parameters from the experimental tests.

Keywords: Performance-Based Seismic Design, Composite Beam, Spectral Displacement, Steel Moment Resisting Frames

1. Introduction

1.1 Background and purpose of study

Recently in the construction industry, the study of the composite structure has actively progressed to improve the economic feasibility of the existing method. Currently, steel-plate concrete composite structure system does not require mold or timbering work while TSC composite beam and TU beam required temporary work and reinforcing bar work; thus, construction cost could be reduced by efficiently trimming its construction period. Due the natural complementary properties of two materials: concrete and steel; the concrete slab is compressively stressed and the steel resists becoming tensile, a steel-concrete composite structure can have a considerable economic cross section. Thus, the best composite material concrete can stress compressively while steel material resists tensile.

The SPC composite beam applied in this study could reduce shear connector by installing bolts by bending steel instead of the original method of welding. However, a study related to earthquake resistant design for SPC composite beam structure had never been progressed. Therefore, in this study, the nonlinear static analysis and the nonlinear dynamic analysis of RC structure, steel structure, and SPC composite beam structure were conducted to compare the seismic performance of SPC composite beam structure.

1.2 Scope and method of study

A five-story office building was used for the analysis. The moment frame system was used to compare frame effects of beam and column. The material design was evaluated using the MIDAS GEN and seismic capacity was evaluated using the PERFORM 3D [1]. For the modeling parameter and acceptable standards of material, the test data of SPC composite beam were used to input the material capacity. The guidelines for seismic performance of existing structure of Korea Infrastructure Safety & Technology Corporation was used for RC and steel structures [2]. The capacity spectrum method (A procedure of ATC-40) was used in the nonlinear static analysis; also, maximum responses of 3 seismic waves were used in the nonlinear dynamic analysis.

2. Evaluation of seismic capacity

2.1 Capacity spectrum method

The capacity spectrum method in ATC40 deducts performance point by crossing both spectrums for capacity and demand. The capacity spectrum is a pushover analysis of Perform 3D that base shear force and roof-top displacement are converted to the spectral acceleration and spectral displacement.

2.1.1 Equivalent static load

In the seismic load of nonlinear static analysis, equivalent static load or mass based load should be applied. In this study, the horizontal load was appended using an equivalent static load formula.

2.1.2 Effectiveness factor and participation factor

An analysis using capacity spectrum method requires eigenvalue analysis as a prior process. The eigenvalue analysis is a calculating process of mode phenomenon (Φ_{mode}), participation factor (PF_{im}), effective mass factor (α_m) of structure.

$$PF_{im} = \left[\frac{\sum_{i=1}^{N} \left(w_i \phi_{im} \right) / g}{\sum_{i=1}^{N} \left(w_i \phi_{im}^2 \right) / g} \right] \quad (1)$$

$$\alpha_m = \frac{\left[\sum_{i=1}^{N}(w_i\phi_{im})/g\right]^2}{\left[\sum_{i=1}^{N} w_i/g\right]\times\left[\sum_{i=1}^{N}(w_i\phi_{im}^2)/g\right]} \tag{2}$$

In here, PF_{im} is a participation factor of m(th)mode on i floor and α_m means effective mass factor of m(th)mode, and w_i/g means mass of i floor. Φ_{im} is the eigen displacement value of m(th)mode on i floor through the eigenvalue analysis. N is the highest story of structure.

2.1.3 ADRS Format Conversion

The participation factor and effective mass factor calculated in the eigenvalue analysis were used for the conversion of ADRS(Acceleration Displacement Response Spectrum). The ADRS conversion is used to convert a base shear force and roof-top displacement (the result value of push over analysis) to Spectral Acceleration (S_a) and Spectral Displacement (S_d) and to convert a period of elastic design spectral method to S_d.

$$S_{ai} = \frac{V_i/W}{\alpha_m} \tag{3}$$

$$S_{di} = \frac{\Delta_{i,roof}}{(PF_{im}\times\varphi_{m,roof})} \tag{4}$$

2.1.4 Calculation of Effective Damping Ratio

Energy dissipation of structure upon seismic load represents an area of hysteresis loop. The ATC-40 assumed an ideal hysteric behavior for rigidity and decrease in strength when applying an attenuation correction coefficient. Such attenuation correction coefficient is classified by the behavior of structure. This study calculated an equivalent damping ratio β_0 with an effective damping ratio β_{eff} using an average structure TYPE C in the Table 1.

$$\beta_0(\%) = \frac{63.7(a_y d_{pi} - d_y\alpha_{pi})}{a_{pi}d_{pi}} \tag{5}$$

$$\beta_{eff}(\%) = \frac{63.7(a_y d_{pi} - d_y\alpha_{pi})}{a_{pi}d_{pi}} + 5 = M_k \bullet \beta_0 + 5 \tag{6}$$

Table 1- Damping modification coefficient, M_k

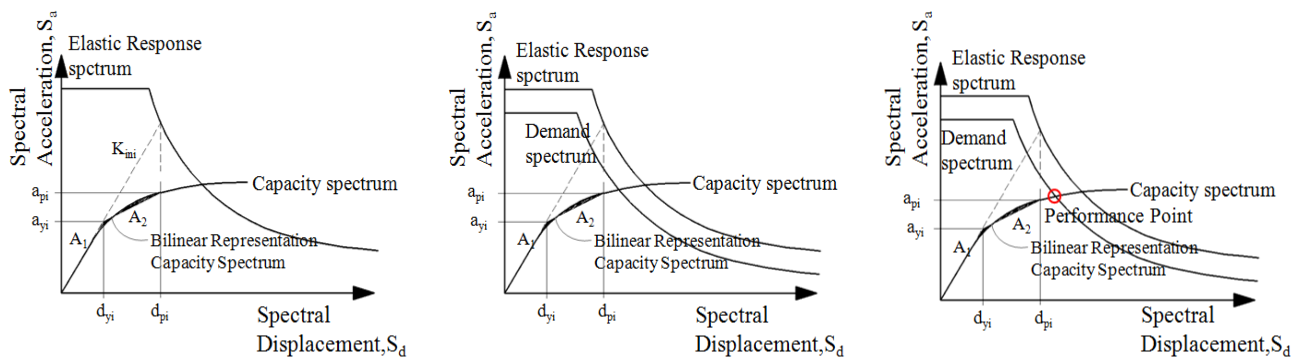
classified by behavior of structure	β0 (%)	M_k
Type A	≦ 16.25	1.0
	> 16.25	$1.13 - \frac{0.51(\alpha_y d_{pi} - d_y\alpha_{pi})}{\alpha_{pi}d_{pi}}$
Type B	≦ 25	0.67
	> 25	$0.845 - 0.446(\alpha_y d_{pi} - d_y\alpha_{pi})$
Type C	Any Value	0.33

2.1.5 Demand Spectrum

A demand spectrum is a spectrum which the regional coefficient '1' of Sc ground was applied as suggested in KBC 2009. In here, 5% damped spectrum crossed over the capacity spectrum [3].

2.1.6 Calculation of Performance Point

The procedure of ATC-40 was used to find a performance point as follows: Extend the initial rigidity of capacity spectrum in ADRS format to 5% of elastic design spectrum and draw a vertical line from an intersection point of the initial rigidity and 5% elastic spectrum cross. Assume an intersection point over the vertical line as an initial performance point (d_{pi}, α_{pi}). Calculate an effective damping ratio with yield point (d_{yi}, α_{yi}) and the initial performance point. Draw a demand spectrum upon effective damping ratio and find an intersection point (d_i, α_i) over the capacity spectrum. Confirm if the intersecting point is within $0.95d_{pi} \leqq d_i \leqq 1.05d_{pi}$. If the intersecting point belongs to the range the point will be a performance point. However, when the intersecting point does not belong to the range, re-calculate an effective damping ration using an initial performance point and yield point .[4].



(a) Process ①~③ (b) Process ④~⑤ (c) Process ⑥

Fig.1 - ATC-40 Capacity Spectrum Method (A-procedure)

2.2 Decision of Performance Level

The Korea Infrastructure Safety and Technology Corporation defines a performance level of structure as Immediate Occupancy level (IO), Life Safety level (LS), Collapse Prevention level (CP), and Collapse. The criteria (Table 2) is the story deformation of structure and material acceptance criteria which indicates requirement level of each performance of structure [2].

Table 2- Allowable Story Drift of Members

structural system	seismic design			non seismic design		
	IO	LS	CP	IO	LS	CP
RC Moment Frame	1.0	2.0	4.0	0.5	1.0	2.0
Steel Moment Frame	0.7	2.5	5.0	0.55	2.0	4.0

3. SPC(Steel Plate Concrete) composite beam

An SPC(Steel Plate Concrete) composite beam has a section phenomenon as shown in Fig 2 below. The SPC co mposite is made by installing bolt into upper bending steel plate and lower U-shape steel in a pair, welding a cap -shape steel on top and placing concrete over the top. A side of bending steel in SPC composite beam resists she ar. In positive moment, a lower steel resisted tensile and upper concrete. In negative moment, an upper rebar resisted tensile and lower steel and concrete resist compression [5].

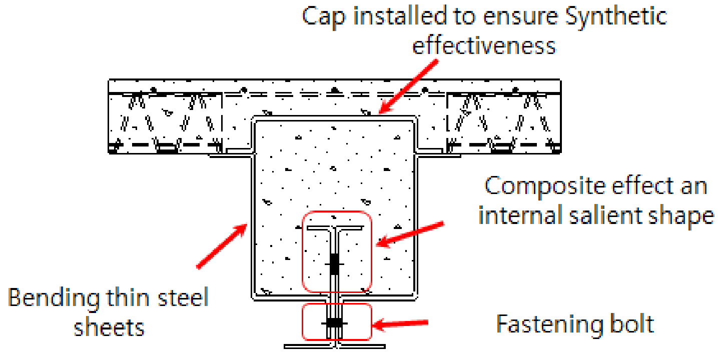


Fig. 2- Configuration of SPC Model

4. Analysis model

4.1 General term of analysis model

Fig. 3 and Fig. 4 below display a ground plan and elevation of analysis model. Fig. 4 is a structure that steel and SPC composite beam had been applied ('SPC'); the SPC has the same plane. The gross area of building is 46,800 ㎜×25,200 ㎜. RC structure includes a girder and beam at 7,800 ㎜ in the X-direction and 8,400 ㎜ the in Y-direction. Additionally, steel and SPC includes a girder and beam at 15,600 ㎜ in the X-direction and 7,800 ㎜ in the Y-direction.

The size of beam and girder is indicated in Table 3. The height of RC, Steel, and SPC structures are all 3,800 ㎜; also, the size of column is indicated in Table 4. (f_{ck}=30MPa, re-bar : SD400 F_y=400MPa, Steel beam & SPC composite beam : SS400, Steel Column-SM490, Dead Load=5kN/m^2, Live Load=5kN/m^2)

4.2 Modeling parameter and acceptable standards of material

The modeling parameter and acceptable standards suggested by FEMA356 were classified into RC material and steel material [6], [7]. In the case of modeling parameter and acceptable standards of RC material, a beam is greatly influenced by reinforced state of the main rebar and applied shear force; also, a column is significantly affected by axial force ratio and applied shear force. In the case of modeling parameter and acceptable standards of steel, a beam is affected by a width-thickness ratio; also, a column is influenced by width-thickness ration and applied axial force ration. However, the FEMA356 did not set up the data of composite beam; also, it suggests to apply to new material based on a test value.

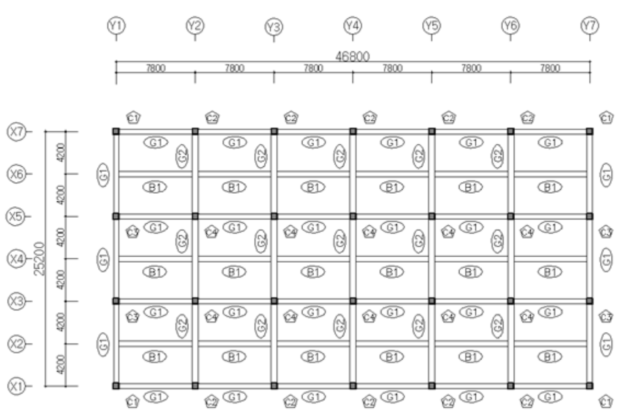


Fig. 3- Configuration of RC Model

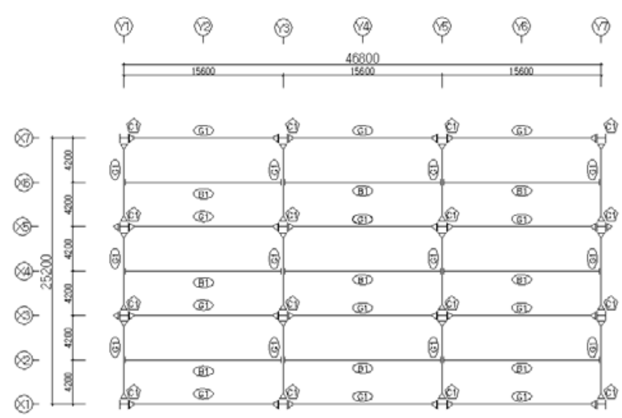


Fig. 4. Configuration of Steel and SPC Model

Table 3 - Girder and Beam Member List

Type	ID	Cross Section	
RC	G1	□-500×800(4-D25,4-D25)	
	G2	I	□-600×800(7-D25,5-D25)
		M	□-600×800(5-D25,5-D25)
		J	□-600×800(7-D25,5-D25)
	B1	□-500×800(4-D25,4-D25)	
Steel	G1	H-588×300×12×20	
	G2	H-588×300×12×20	
	B1	H-792×300×14×22	
SPC	G1	360×650×4.5×9	
	G2	360×650×4.5×9	
	B1	360×650×4.5×9	

Table 4. Column Member List

Type	Floor	ID	Cross Section
RC	1 ~ 3F	C1	□-650×650(14EA-5-D25)
		C2	□-650×650(20EA-5-D25)
		C3	□-650×650(24EA-7-D25)
		C4	□-650×650(22EA-7-D25)
	4 ~ RF	C1	□-550×550(12EA-4-D25)
		C2	□-550×550(14EA-5-D25)
		C3	□-550×550(16EA-5-D25)
		C4	□-550×550(16EA-5-D25)
Steel	1 ~ RF	C1	H-428×407×20×35
SPC	1 ~ RF	C1	H-428×407×20×35

4.3 Definition of Modeling Parameter and Acceptable Standards of SPC composite beam

4.3.1 Test method

The steel concrete composite beam used in the SPC structure is shown in the Fig. 5. The Fig. 6 is a method to apply the load in the test. The test was progressed through a cycle load test of the beam-column node and the link-column node of 0722.2 KBC2009 [3]. To measure a ration angle, installed LVDT 1~6 as shown in Fig. 7 and collected the data.

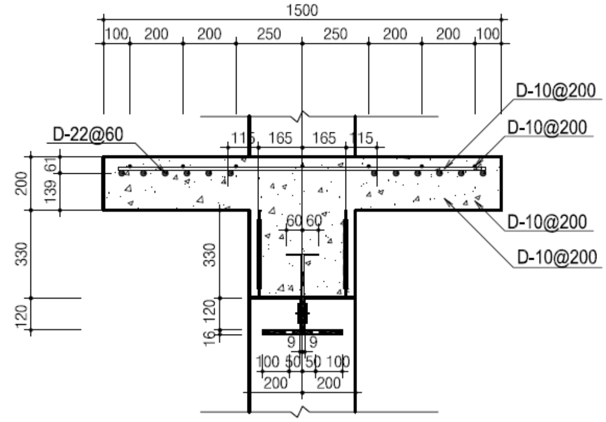


Fig. 5 - Configuration of SPC Cross section

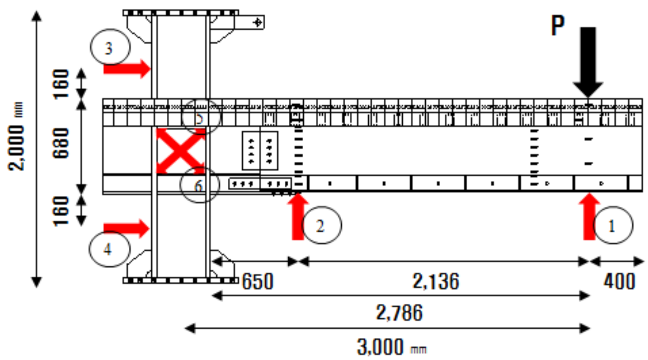
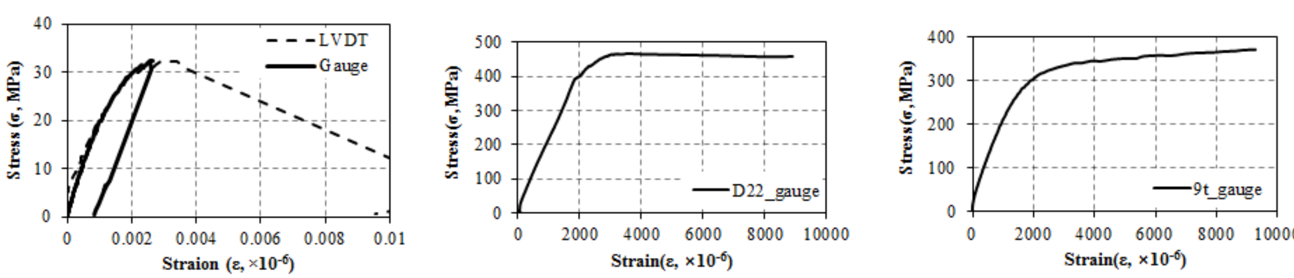


Fig. 6 - Configuration of SPC Model

Fig. 7 – Cyclic loading test of specimen

4.3.2 Material Test of SPC composite beam

The following Fig 8 (a) is the compressive strength test result of concrete. The maximum compressive strength of concrete (LVDT and gauge used) satisfied 32.4 MPa, as well as indicating 0.00257 as the maximum strain ratio. The Fig 8 (b) is the tensile strength test result of the deformed bar. The yield strength of deformed bar (LVDT used) satisfied 467.6 MPa; also showed of 0.00302 strain ratio in yielding. The Fig 8 (c) is the tensile strength test result of steel. The maximum tensile strength (gauge used) satisfied 371.7 MPa; also proved a 0.00952 of maximum strain ratio.



(a) Concrete test piece (b) Deformed bar (D22) (c) steel plate (thickness: 9 mm)

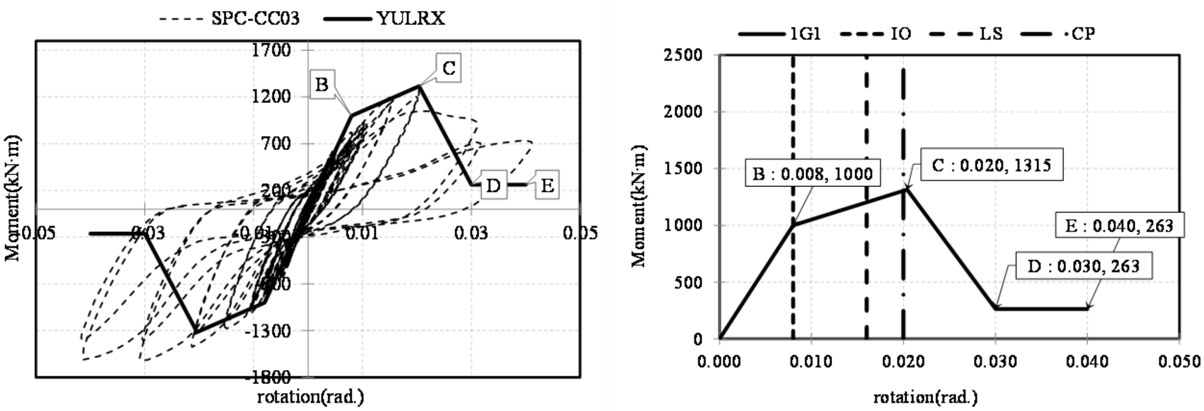
Fig. 8 - Stress-Strain Curve of coupon

4.3.3 Modeling variable

The Fig. 9 (a) indicates hysteresis curve of SPC composite beam in an equal size and input YULRX graph at Perform 3D. The YULRX graph extended an initial rigidity of hysteresis curve to the yield moment and the plastic moment. Beyond the plastic moment, the coordinate and 0.2Mp extended at a 0.8Mp point of rotation angle to the maximum rotation angle.

4.3.4 Acceptable standards

The acceptable standards of material set a yield moment to IO level, CP to plastic moment, and LS level to 2/3 of IO and CP.

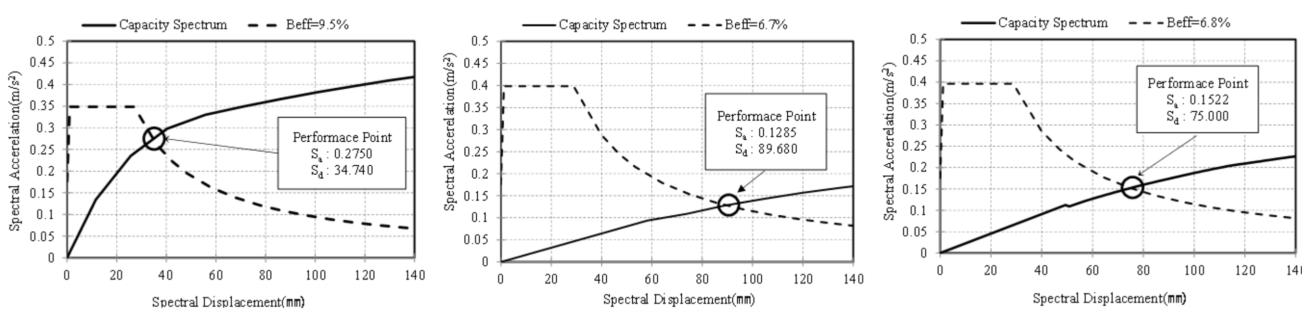


(a) Experimental Value (b) SPC input Curve

Fig. 9 - SPC Modeling Parameter and Acceptance criteria

4.4 Calculation of Performance point

The Fig. 10 shows the performance point of each structure. The RC structure showed Sa = 0.2750, Sd = 34.740 of performance point at 9.5% effective damping ratio of the elastic design spectrum. The steel structure showed Sa = 0.1285, Sd = 89.680 of performance point at 6.7% effective damping ratio of the elastic design spectrum. The SPC structure showed Sa = 0.1522, Sd =75.000 of performance point at 6.8% effective damping ratio of the elastic design spectrum.



(a) RC Structure (b) Steel Structure (c) SPC Structure

Fig. 10 - Performance point of Structure

4.5 Nonlinear Dynamic Analysis

The nonlinear dynamic analysis used seismic waves from El-Centro, Northridge, and San Fernando. The peak ground acceleration (PGA) was applied adjusting the scale to 0.2g considering minor earthquake. Table 5 shows the performance of structure through the maximum response of 3 seismic waves. Each performance was determined according to story strain ratio and acceptable standards of material.

Table 5 - Scale Factor (0.2g)

Earthquake	Scale Factor	
	X-way	Y-way
El centro	0.9337	0.5604
Northridge	0.5413	0.2267
San Fernando	1.4093	0.7852

5. Analysis result and analysis

5.1 Result and Analysis of nonlinear static analysis

Story strain of structure at the relevant performance point is indicated in Table 6. Each structure showed the maximum strain at the maximum height of 1F column. Such maximum strain values are arranged by story drift criteria of IO (Immediate Occupancy) level, LS (Life Safety) level, and CP (Collapse Prevention) level as below. The RC structure showed IO = 0.5%, LS = 1%, CP = 2%. The Steel and SPC structure showed IO = 0.7%, LS = 2.5% CP = 4%. The Fig 11. ~ Fig 16. is the result of the nonlinear static analysis that RC satisfied IO level with 0.38%, the steel satisfied LS level with 1.13%, and the SPC satisfied LS level with 1.15%.

Table 6 - Floor Drift (max) of Nonlinear Static Analysis

	RC(%)	Steel(%)	SPC(%)
RF	0.1056	0.2108	0.1452
5F	0.2167	0.3688	0.2608
4F	0.2897	0.4994	0.3561
3F	0.3616	0.6447	0.4633
2F	0.3842	1.1328	1.1509
1F	0	0	0

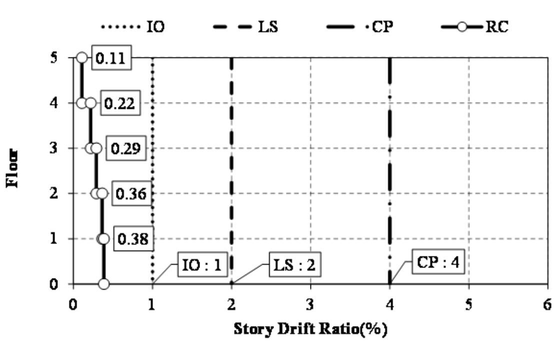


Fig. 11 - RC Floor Drift

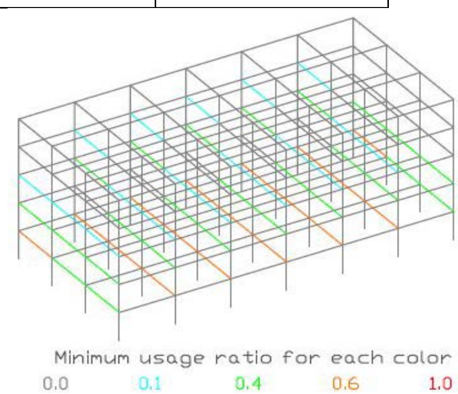


Fig. 12 - RC member acceptable level

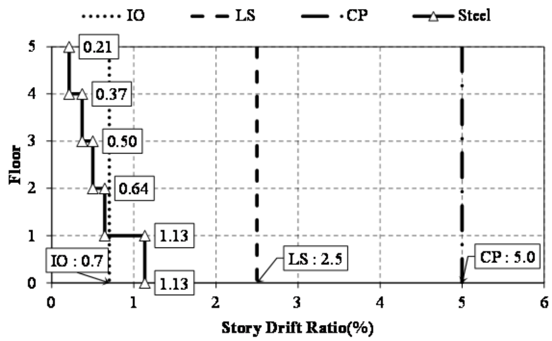


Fig. 13 - Steel Floor Drift

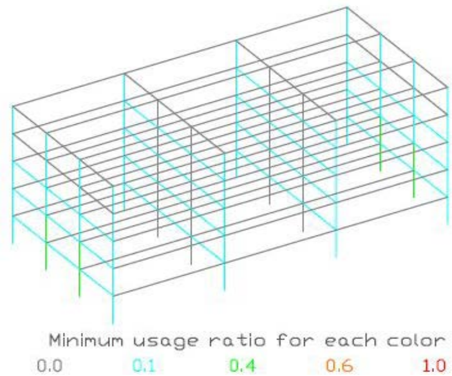


Fig. 14 - Steel member acceptable level

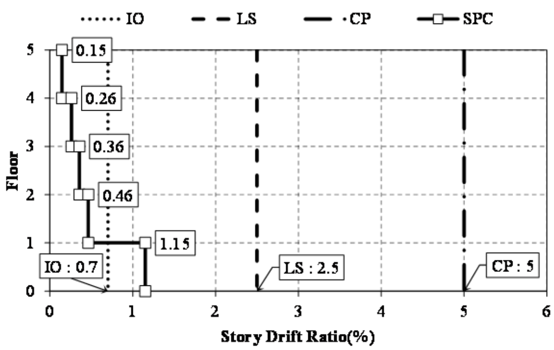


Fig. 15 - SPC Floor Drift

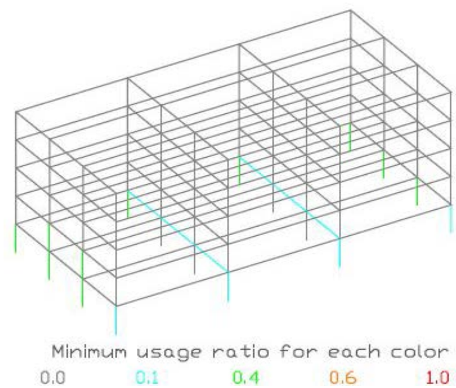


Fig. 16 - SPC member acceptable level

5.2 Result and analysis of nonlinear dynamic analysis

5.2.1 El Centro seismic wave

A story deformation of RC structure in X-direction satisfied 0.54% on 1st floor, 0.46% on 2nd floor, 0.28% on 3rd floor, 0.15% on 4th floor, and 0.06% on 5th floor; also, in the Y-direction, satisfied 0.38% on 1st floor, 0.36% on 2nd floor, 0.26% on 3rd floor, 0.17% on 4th floor, and 0.06% on 5th floor. Story deformation of RC structure deducted IO level. For the acceptable standards of RC structure, horizontal girder satisfied 40% at LS level. Thus, The RC structure showed LS level.

A story deformation of Steel structure in X-direction satisfied 1.04 % (1st floor), 0.81 % (2nd floor), 0.72 % (3rd floor), 0.48 % (4th floor), and 0.31 % (5th floor); also, in the Y-direction, satisfied 0.94 % (1st floor), 0.49 % (2nd floor), 0.42 % (3rd floor), 0.32 % (4th floor), and 0.18 % (5th floor). Thus, a story deformation performance of steel structure satisfied LS level. For the acceptable standards of steel structure, 40% of LS deformation level was shown in the exterior column. The performance of steel structure showed LS level.

A story deformation of SPC structure in X-direction satisfied 0.85 % (1st floor), 0.62 % (2nd floor), 0.51 % (3rd floor), 0.35 % (4th floor), and 0.19 % (5th floor); also, in the Y-direction, satisfied 0.85 % (1st floor), 0.30 % (2nd floor), 0.19 % (3rd floor), 0.11 % (4th floor), and 0.05 % floor. The story deformation of SPC structure satisfied LS level. For an acceptable level of material, 40% of LS deformation level was shown in the exterior column. The performance of steel structure showed LS level. For the acceptable level of SPC structure, the exterior column in the center of 1st floor exceeded 40 %; also, there was no material exceeding the LS level. Thus, the performance of SPC structure satisfied LS level. The story deformation of El Centro seismic wave is shown in the Fig. 17 and Fig. 18.

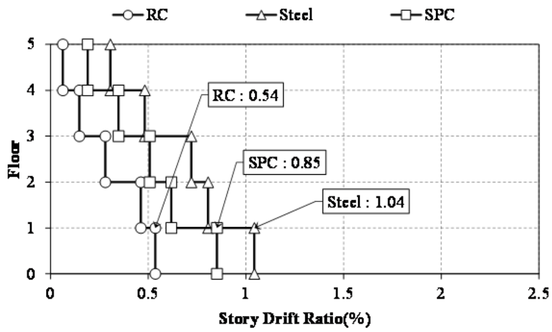


Fig. 17 – El centro 0.2g X-direction

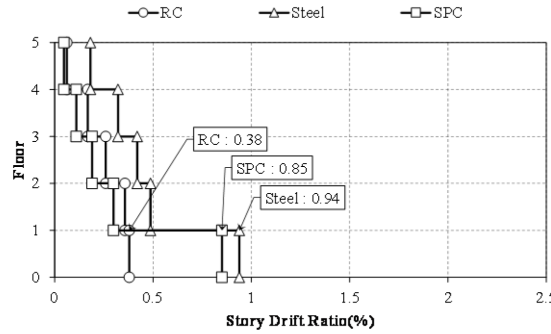


Fig.18 – El centro 0.2g Y-direction

5.2.2 Northridge seismic wave

A story deformation of RC structure in X-direction satisfied 0.25 % (1st floor), 0.18 % (2nd floor), 0.14 % (3rd floor), 0.13 % (4th floor), and 0.09 % (5th floor); also, in Y-direction, satisfied 0.08 % (1st floor), 0.06 % (2nd floor), 0.05 % (3rd floor), 0.06 % (4th floor), and 0.05 % (5th floor). A deformation of RC structure deducted IO level. For the acceptable level of material, the horizontal girder on 2nd floor exceeded 10% at IO level. The performance of RC structure indicated as IO level.

A story deformation of steel structure in X-direction indicated as 0.79 % (1st floor), 0.66 % (2nd floor), 0.51 % (3rd floor), 0.39 % (4th floor), and 0.26 % (5th floor); also, in Y-direction, indicated as 0.69 % (1st floor), 0.38 % (2nd floor), 0.30 % (3rd floor), 0.21 % (4th floor), and 0.11 % (5th floor). Thus, the story deformation level of steel structure satisfied LS level. For the acceptable level of steel structure, material exceeding 10% at the LS deformation level was shown in a beam and column. A level of steel structure showed LS level.

A story deformation of SPC structure in X-direction indicated as 0.68 % (1st floor), 0.49 % (2nd floor), 0.39 % (3rd floor), 0.27 % (4th floor), and 0.14 % (5th floor); also, in Y-direction, indicated as 0.49 % (1st floor), 0.19 % (2nd floor), 0.15 % (3rd floor), 0.10 % (4th floor), and 0.06 % (5th floor). A story deformation level of SPC structure satisfied IO level. For the acceptable level of material, material exceeding 10% at LS deformation level in the exterior column and the horizontal girder on the 2nd floor. A story deformation of SPC structure satisfied the IO level, but also, satisfied the LS level. Thus, the performance of SPC structure satisfied LS level. The story deformation of Northridge seismic wave is shown in the Fig. 19 and Fig. 20.

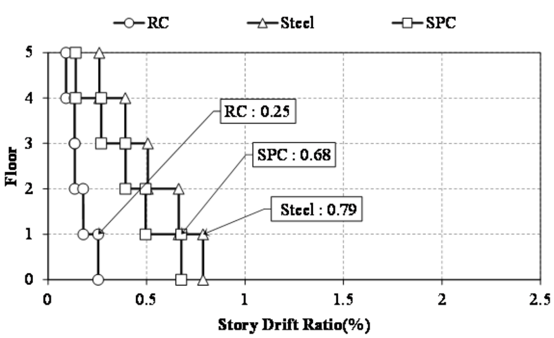


Fig. 19 - Northridge 0.2g X-direction

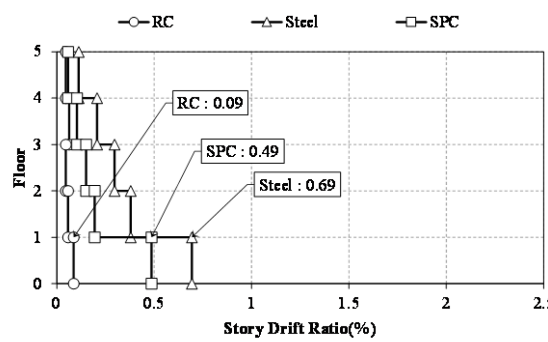


Fig. 20 - Northridge 0.2g Y-direction

5.2.3 San Fernando Seismic wave

A story deformation of RC structure in X-direction indicated as 0.40 % (1st floor), 0.27 % (2nd floor), 0.12 % (3rd floor), 0.08 % (4th floor), and 0.11 % (5th floor); also, in the Y-direction, indicated as 0.48 % (1st floor), 0.44 % (2nd floor), 0.30 % (3rd floor), 0.18 % (4th floor), and 0.07 % (5th floor). The story deformation of RC structure deducted the IO level. As the acceptable level of material exceeded the IO level, the horizontal girder on 2nd floor satisfied 40% at the LS level. The performance of RC structure satisfied the LS level.

A story deformation of steel structure in X-direction indicated as 1.72 % (1st floor), 1.59 % (2nd floor), 1.32 % (3rd floor), 0.92 % (4th floor), and 0.59 % (5th floor); also, in the Y-direction, indicated as 1.75 % (1st floor), 1.16

% (2nd floor), 0.90 % (3rd floor), 0.59 % (4th floor), and 0.30 % (5th floor). Thus, the story deformation level of steel structure satisfied the LS level. The acceptable level of material exceeded the IO level and the LS level; also, there was a column satisfying 60% of CP level. The performance of steel structure satisfied the CP level.

A story deformation of SPC structure in X-direction indicated as 1.41 % (1st floor), 1.05 % (2nd floor), 0.76 % (3rd floor), 0.48 % (4th floor), and 0.22 % (5th floor); also, in the Y-direction, indicated as 2.28 % (1st floor), 0.70 % (2nd floor), 0.37 % (3rd floor), 0.20 % (4th floor), and 0.10 % (5th floor). The story deformation level of SPC structure satisfied the LS level. The acceptable level of material also exceeded IO level and LS level; also, the exterior column on 1st floor satisfied 60% in the CP level. The story deformation level of SPC satisfied LS level; however, the acceptable level of material satisfied the CP level exceeding the LS level. Thus, the performance level of SPC structure satisfied the CP level. The story deformation of San Fernando seismic wave is shown in the Fig. 21 and Fig. 22.

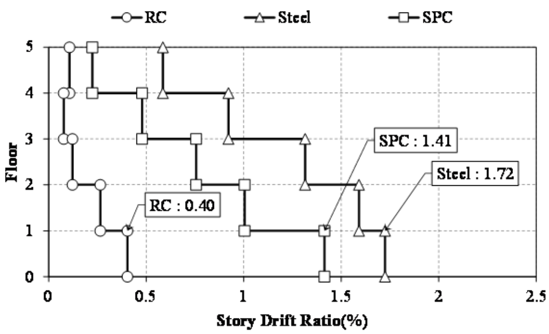


Fig. 21 - San Fernando 0.2g X-direction

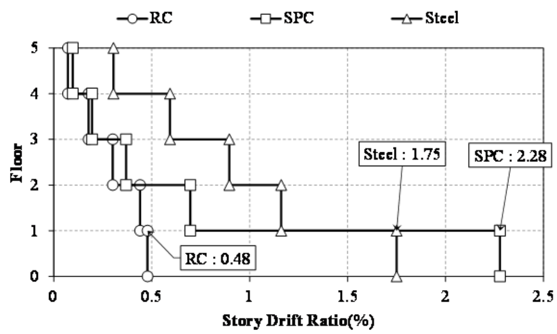


Fig. 22 - San Fernando 0.2g Y-direction

5.2.4 Material Performance level

The performance level of material upon nonlinear static analysis and nonlinear dynamic analysis are as shown in Table 9. As a result of the nonlinear static analysis, the material of RC structure satisfied the IO level. However, in the nonlinear dynamic analysis, the El Centro seismic wave and the San Fernando seismic wave satisfied the LS level exceeding the IO level. The nonlinear static analysis result of Steel structure satisfied the LS level; however, the acceptable level of material in the San Fernando seismic wave satisfied the CP level exceeding the LS level. The nonlinear static analysis of SPC structure satisfied the LS level; also, the acceptable level of material in San Fernando seismic wave in the nonlinear dynamic analysis satisfied the CP level exceeding the LS level.

Table 6 - Seismic Performance Level

	RC	Steel	SPC
Nonlinear Static Analysis	IO	LS	LS
El centro	LS	LS	LS
Northridge	IO	LS	LS
San Fernando	LS	CP	CP

6. Conclusion

In this study, to evaluate the seismic performance of long span composite beam (SPC), repeated cycle test value was applied to the Peform3D. Under 0.2g seismic condition, the seismic performance of composite beam structure was compared with steel concrete structure and steel structure. The followings are the result.

(1) The SPC structure showed the greatest story deformation ratio (%) of nonlinear static analysis and followed by the steel structure and RC structure in order. A column on the 1st floor showed the biggest story deformation ratio. The RC structure showed the least story deformation ratio due to its short span interval and the largest number of column (16 columns more than other).

(2) In the nonlinear static analysis, the steel structure and the SPC structure has the equal span interval. The SPC structure showed the biggest story deformation ration but showed less story deformation ration on the 2nd floor and above. The SPC composite beam controlled the story deformation following the greater rigidity value than girder of the steel structure.

(3) In the nonlinear static analysis, the performance level over the story deformation ration satisfied the IO level in the RC structure, the LS level in the steel structure, and the LS level in the SPC structure. For the acceptable level of material, the RC structure satisfied the LS level; the steel structure satisfied the level LS level; the SPC structure satisfied the LS level.

(4) In the nonlinear dynamic analysis, the steel structure showed the greatest maximum story deformation ration followed by SPC and RC structures except the San Fernand seismic wave. The RC structure showed less story deformation ratio at all stories than other structures. Also, the SPC structure showed less story deformation ratio at all stories than the steel structure. However, in the San Fernand seismic wave, the SPC structure showed bigger story deformation ratio with 2.28% than the steel structure.

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