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Response of RC Beam-Slab Structure Strengthened with CFRP under Sudden Corner Column Removal Scenario

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Abstract: Reinforced concrete columns support loads from beam-slab sub assemblage of a buildings and transfer into a foundation. However, columns could also be intentionally removed due to architectural interest, accidentally lost by unexpected extreme loading such as blast or impact loading or construction error leading a structure to fail progressively. A missing corner column likely causes progressive collapse than an interior column or edge column due to relatively weak tie force from nearby structural member. Applying innovative strengthening methods such as using Carbon Fiber-reinforced polymer (CFRP) composites is one of viable options to restore or increase performance losses due to a missing column.

This research work numerically investigates response of as-built and Carbon Fiber-reinforced polymer (CFRP) composites strengthened beam-slab sub assemblage under sudden corner column removal scenario. Non-linear finite element software program ANSYS is used to generate 3D model and validate experiment results reported in literature and further parametric studies are performed on retrofitting techniques to restore or enhance load carrying capacity and floor stiffness of beam-slab sub assemblage under missing column case.

Finite element results indicate as compared to beam-slab sub assemblage with all columns intact, applying 16 CFRP layers (0.334mm thickness per layer) at slab top, beam side and bottom of beam-slab sub assemblage with missing corner column resulted in 87.36% gain in load carrying capacity. Also use of composites improved failure characteristics such as crack pattern, concrete damage and progressive collapse resistance of beam-slab sub assemblage.

Author Keywords: Reinforced concrete beam-slab structure, Progressive collapse, Finite element analysis (FEA), ANSYS, Concrete Microplane material model, Carbon fiber reinforced polymer (CFRP)

I. INTRODUCTION

The columns that supported the horizontal member intentionally removed due to Architectural interest or the columns accidentally lost due to unexpected loads and failed progressively. Different literatures study the cause and effect of progressive collapse of reinforced concrete building and also the literatures study the progressive collapse of some portion of structure by extracted from total building in sudden removal column scenario. The different failure mechanism from starting to local bending failure which were flexural action, tensile membrane action, one-way catenary and dowel action to resist the applied load and also 98% of the applied concentrated loads was transferred to the edge columns when the central column removed suddenly studied by (Huizhong et.al, 2018).The progressive collapse of beam-slab subassemblies structure when the corner column lost suddenly under concentrated load at the above lost column and distributed load on the slab studied by (Namyo, 2017) and (Pham et.al, 2017),respectively. The Progressive collapse and strengthened of beam-slab subassemblies in a corner column removal scenario studied by (Feng et.al,2019) and also investigate the behavior of progressive collapse after strengthened by externally bonded GFRP laminated and near surface mounted (NSM) GFRP bars.

In the United States the interest in fiber-based reinforcement for concrete structures started in 1930's. However, actual development and research activities into the use of FRP materials for retrofitting concrete structures started in the late 1980's (Rizigalla et.al, 2003). FRP materials have quickly moved from the state-of-the art to mainstream technology and their applications in many fields had started (Busel J.and Barno, 1995). In addition, there is continuous research done by the state department of transportation (DOTS) for pursuing the use of FRP for repair and retrofit of transportation structures (NCHRP, 2003). In 2002 the ACI Committee 440 developed a guide (ACI Committee 440, 2002) for the design and construction of externally bonded FRP systems for strengthening concrete structures. The correct combination used bottom and side CFRP plates strength of Beam, with proper epoxy, the ultimate load become doubled and reduce diagonal crack and also prevent rupture within the flexure (horizontal) strength fibers (Grace et.al 1999) and (Wang and Guo,2005). Strengthening of structurally damaged and undamaged wide, shallow RC beam that are unremarkably employed in the joist flooring system, using outwardly secure CFRP Plates (Ahemed et.al, 2014). The effectiveness of strengthened reinforced concrete Beams by different combination polymer that are CFRP, GFRP and JFRP (jute fiber polymers) in several sides are investigated by (Fakhreddine et.al, 2016).The result of discontinues FRP sheets (FRP Strips) compared with continued FRP sheets were investigated in shear strength of RC T-beams by (Amir and Omar, 2011). The impact of CFRP and TRM strength polymer in damage pattern, Load-Displacement Variation and Energy Absorption during punching shear are investigated by (Husain et al, 2015) .Strength of two-way concrete slab using FRP (CFRP and GFRP) materials to improve the flexural capability or load carrying capacity by (Ebead et.al, 2002). The restoration of load caring capacity slab that has hole using CFRP sheet study by (Shehab et.al, 2017).Effectiveness of, will increase shear strengthens and altered of brittle failure to flexure mode failure using Self-manufactured CFRP sheet dowels were placed around the column stubs of the flat slab studied by (Erdoğan et.al, 2007).The impact of cyclic and monotonic load of punching strength of flat slabs reinforced with Carbon Fiber strengthened polymer (CFRP) sheets and the result of reinforcement ratio under cyclic load strengthen with CFRP sheets is studied by (Esfahani, 2008). The effectiveness of the degree of CFRP stripes at the tension face of the reinforced concrete flat slab throughout sudden removal of corner column against progressive collapse investigate by (Qian and Li, 2013).

II. NUMERICAL MODELS OF BEAM-SLAB STRUCTURES UNDER PROGRESSIVE COLLAPSE

(Feng et.al, 2019) And (Namyo, 2017) studies the progressive collapse of beam-slab subassemblies under corner quasi-static load above the removed column and (Pham et.al, 2017) studies 8-point load on the slab having the assumption of pertaining uniformly distributed load. From the above mentioned researches the study done by (Pham et.al, 2017)on a progressive collapse of slab during the sudden removal of column under uniformly distributed load found to be more realistic to study. A finite element modeling software, ANSYS mechanical APDL 19.0 (ANSYS-19, 2017) is used for the research and the constitutive modeling of concrete and reinforcement material, boundary conditions and loading techniques and is validated by verifying the model.

A. *Experimental Specimens For Verification*

The simulation techniques of numerical analysis (Finite element) modeling supported by validation. in this paper the validation carried out to verify the reliability of ANSY APDL 19.0 (ANSYS-19, 2017) in the progressive collapse of Beam-slab sub assemblage under the corner column lose scenario which is tested by (Namyo, 2017) and (Pham et.al, 2017) for corner concentrated load above the lost column and for 8-point by assume like distributed load on the slab respectively. Due to laboratory space constraint, the sub assemblage was scaled to 2/5 scale. The section size, concrete cover, Reinforcement ratio of the non-seismic design proto type and control specimen are given in Table 1. The same value of reinforcement ratio is used in both the prototype and model frames.

The schematic structural drawing for tested specimen in the laboratory based on the above scaled down sectional size and reinforcement ratio. The slab part of the specimen extends 290mm from center in both directions to providing bending negative bending moment and also the thickness increases to 120mm to simplified the actual boundary condition.

Table 1 The Section size and design output used in prototype and the tested specimen *(Pham et.al, 2017)*

Sectional Size		
Type	Prototype Structure	Tesed Specimen
Slab(mm)	6000×6000×200	2400×2400×80
Beam(mm)	3000×5000	100×180
Column(mm)	450×450	180×180
Beam Reinforcement Ratio		
Top(%)	1.297	1.548
Bottom(%)	0.85	1.012
Stirrup(%)	0.251	0.331
Column Reinforcement Ratio		
Longitudinal(%)	1.432	1.53
Stirrup(%)	0.199	0.194
Slab Reinforcement Ratio		
Middle Strip Bot(%)	0.27	0.29
Interior Strip Top(%)	0.199	0.194
Exterior Strip Top(%)	0.21	0.29
Concrete Cover		
Beam,Column and Slab(mm)	30,30,20	15

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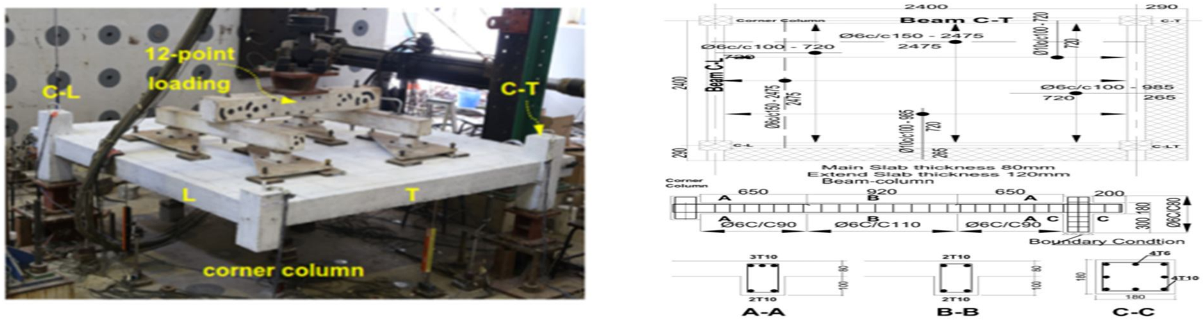

a) b)

Fig.1 Specimen design a) experimental 3-D view b) structural details of the control specimen *(Pham et.al, 2017)*

Table 2 Material properties (Pham et.al, 2017)

Material	Size	Bar Type	Elastic Modulus (Gpa)	Yield Strength (Mpa)	Ultimate Strength (Mpa)	Fracture Strain(%)
Reinforcement Steel	T10	Deformed	200	507	609	11
	R6	Smooth	200	400	583	25
Concrete Cylindrical Strength			Compressive Strength(Mpa)			32
			Splitting Tensile Strength(Mpa)			3.7
			Elastic Modulus(Gpa)			26.6

III. FINITE ELEMENT FORMULATION AND MATERIAL MODELING

The 3-D modeling of frame with slab is necessary to evaluate the response under progressive collapse removal column scenario. Concrete block modeled using CPT215 3-D 8-Node Coupled Pore-Pressure-Thermal Mechanical Solid element type which support the coupled damage- Plasticity micro material model and it have capability of material elasticity, stress stiffening, large deflection, and large strain .CPT215 element type have three translation degree of freedom in X,Y and Z direction and in addition to two pore-pressure and temperature degree of freedom per node. Reinforcement model using REINF264 3-D Discrete Reinforcing Element Type and the nodal locations, degrees of freedom, and connectivity of the REINF264 element are identical to those of the base element which is CPT215 solid element.

The based behavior consideration to select CFRP element type used for finite element modeling for this study is can be used for layered applications for modeling, applicability for large strain non-linear analysis and supported full integration schemes in the element domain.SHELL181 element type where selected from ANSYS element library and which are fulfill this criteria.SHELL181 have for node and have six degree of freedom per node which are Ux, Uy, Uz, Rx, Ry and Rz. However, the best things that have membrane option to change the degree of freedom to only translation to form homogenic nodal behavior to the concrete element CPT2015 which have only translation degree of freedom per node.

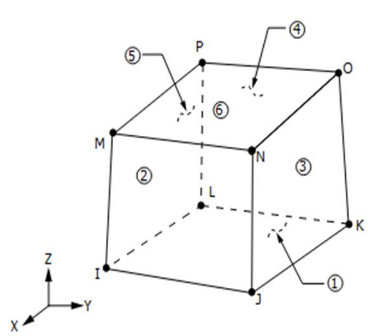

Fig.2 CPT215 Solid Element Type for concrete (ANSYS-19, 2017)

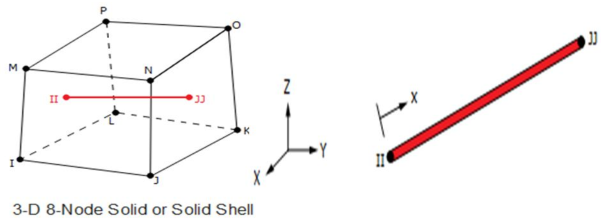

Fig.3 REINF264 Element Type for Reinforcement (ANSYS-19, 2017)

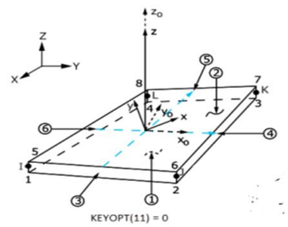

Fig.4 SHELL181 Element Type for CFRP (ANSYS-19, 2017)

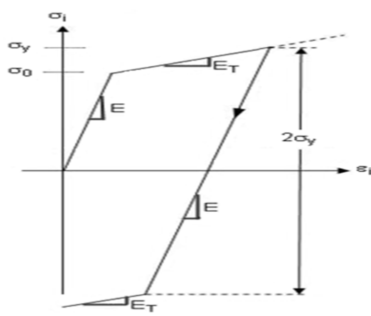

Figure 5 Bilinear isotropic hardening plasticity material model for Reinforcement *(ANSYS-19, 2017)*

Table 3 Reinforcement Bilinear isotropic hardening plasticity Values

	T10	R6
E(Mpa)	200000	200000
ET(Mpa)	1000	1000
δ(Mpa)	507	400

Table 4 Coupled damaged plasticity Microplane Model of Concrete parameter values

Elasticity						
E(Mpa)	v	ρ(Kg/mm^3)				
26000	0.2	2.40E-06				
Plasticity						
f_{uc}(Mpa)	f_{bc}(Mpa)	f_{ut}(Mpa)	R_T	D(Mpa)	sigVc0(Mpa)	R
C1	C2	C3	C4	C5	C6	C7
32	36.4	3.7	1	40000	-24	2
Damage						
gamt0	gamc0	betat	betac			
C8	C9	C10	C11			
0	2.00E-06	4.00E+03	2.50E+03			
The nonlocal parameters						
c	m					
C1	C2					
1600	2.5					

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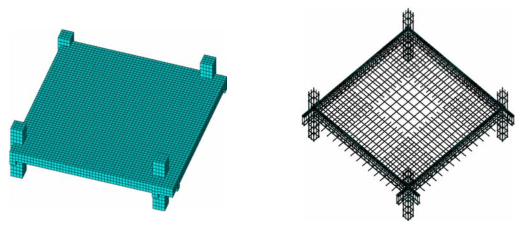
Table 5 CFRP Geometric and Material Property values *(System, 2015)*

Type	Nominal thickness (mm)	Tensile strength (MPa)	Elastic Modulus (GPa)	Elongation (%)	Standard Width (cm)	Standard length of roll (m)
Uni-directional CFRP C-Sheat 240	0.334	3800	240	1.8	10	50

A. Geometry and Meshing

The geometry is not comfortable for symmetric so full model is adapted and the solid element with the reinforcing element is attached to the node so that no special bond contact is taken into account between concrete and steel. All CPT215 concrete element meshed by Squair size 50mm using LESIZE command.

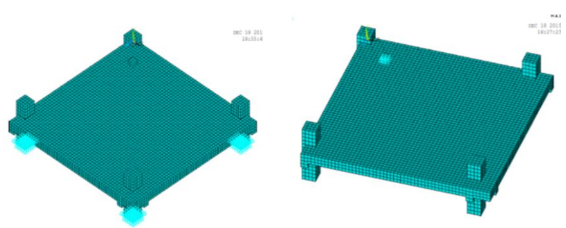


a) b)

Fig.6 FE 3-D modeling of Experimental specimen a) Concrete and b) Reinforcement

B. Boundary Condition

The slab thickness was 80 mm, while the neighboring slab rotational constraints were expressed by a thicker slab section (120 mm) extending beyond the parameter beams by 240 mm. The columns C-L, C-T and C-L-T where pined to steel supports which in turn bolted to the strong floor in experimental specimens. This boundary condition simulates in finite element modeling by assign the degree of freedom Ux, Uy and Uz equal to zero at each node in the bottom of C-L, C- T and C-L-T columns and extend the slab with increase the thickness used also slab rotational constraint like experimental setup.



a) b)

Fig.7. Boundary condition in FEM, b) Location of applied displacement loading

C. Loading and Solving Methodology

In this study, an implicit finite element nonlinear quasi-static (monotonic) analysis based on displacement control mechanism by applying a displacement of 300mm which was the final displacement at V1 from the diagonal displacement profile of the slab when test stopped (Pham et.al, 2017). The location of V1 is near to the loosen corner column and also in experiment specimen from eight-point loading position one of them is near to loosen the corner column. This displacement applied to a corresponding loading position in experiment setup which is near to the loosen column by crating loading plate.

The loading plate has 100mm*100mm*80mm sectional dimensions rest on the slab at the location of 400mm in X and Z ordinate direction that far from the origin (Fig.7b) and also assign the T10 Reinforcement steel material property to the loading plate. The solution control has defined a number of subtypes which is used for iterate analysis and also analysis is geometrically nonlinear, the stress stiffening is included in the solution control by on large displacement static (NLGEOM, ON).

Numerical analysis of reinforced concrete structures is customarily performed by static implicit FE solvers where the integration scheme is for example full Newton-Raphson. This implicit equation can be solved iteratively at each time level before moving to the next time step and provide convergence at the end of each load increment within tolerance limits.

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D. Results Discussions on The Validation of FE Analyses

1) *Discussions on Load-Displacement Behavior:* The Loading Test results separated into two phases, the primary stage when the down corner column displacement was less than one beam depth (180mm) which suggests CA in beams and TMA in slabs were activated. The other second stage, which is bigger than 180mm, the beams and the slabs would have gone into tensile systems. Fig.8 shows that Load-Displacement Response of FE analysis results validate to Experimental result which was studied by (Pham et.al, 2017). The Finite element Numerical analysis considers two control specimens Based on experimental result which are the three columns does not damage under uniform distributed load tested. one of the analyses is the specimen with a Reinforced concrete column, which consume 6hrs to finalize the result and the other one is the column material changed to linear steal plate element which decrease the analysis time to 1hr. The two analysis has almost similar load deflection behavior and maximum load carrying capacity rather than the final load at the final displacement. This study, the main objectives are increased of the maximum load carrying capacity. After validate the two FE methodology of the experiment, the control specimen which is the FE analysis of Beam-Slab sub assemblage with the steel plate column is selected for result desiccation and the parameter study since it is more effective to manage the time requirements.

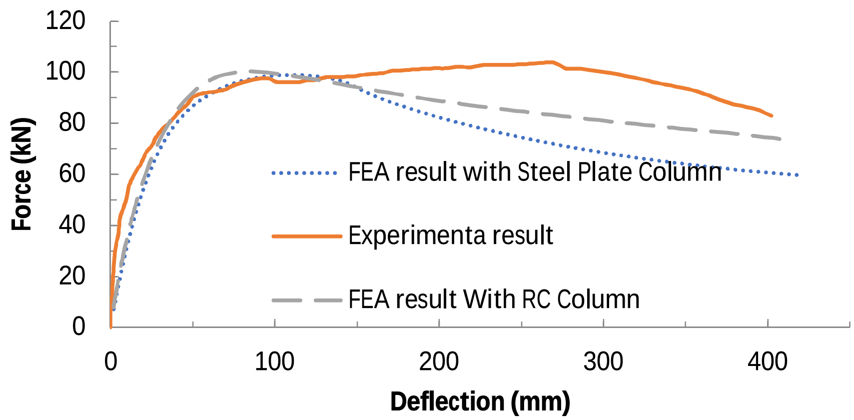


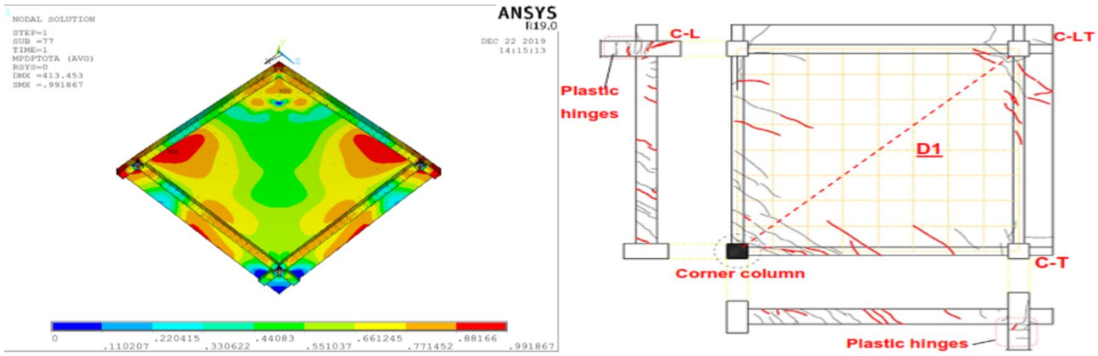
Fig.8.Validation Results of Load-Displacement Response

The stage-1 scenario, load-displacement increase almost linearly from 0KN to 45KN, which is the same behaviors in FE and Experimental analysis. The end of stage-1 which the specimens deflected almost half of beam depth, the experiment result attained the first peak load of 97KN at displacement of 97mm.likewise Experimental result, The FE analysis scored 99.3KN at the end of stage-1 about 97mm displacement with the percentage of error difference of -2.32%. The load-displacement behavior in the experiment after stage-1, the load capacity increased to 103.85KN with increased displacement of 269mm.Pham et.al, (2017) discussed that the reason of this increment of load in stages-2 are the mobilization of the two tensile action which is a CA and TMA action in Beams and Slabs, respectively. However, in FE analysis the result shows that the load carrying capacity decreased after stage-1 and scored 84KN at 269mm which is the displacement that corresponding maximum load in Experiment result.

Generally, The Maximum load carrying capacity of the control specimen which is the corner column missed suddenly, tested under distributed load in the experiment was 103.85KN and the maximum load in FE analysis of the control specimen with column replaced by steel plate is 99.3KN with the percentage difference of about -4.3%, which is acceptable.

Due to safety reasons the experimental test stopped at the corner column displaced 400mm when the load was reduced to 85KN (Pham et.al, 2017).however, in FE analysis 81.4KN and 60.7KN are the residual load result of the FE with RC and Steel plate columns respectively.

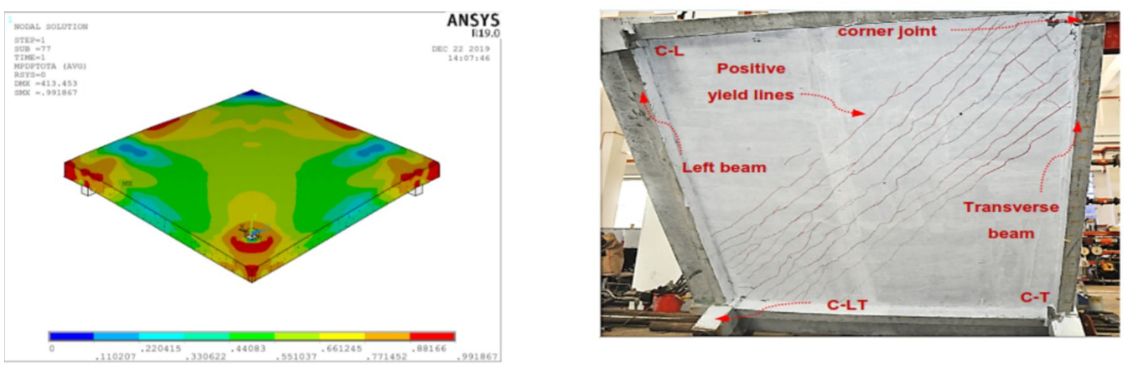
2) *Discussions on Damage Pattern Behavior:* The crack initiation and propagation of experimental test results, S-COR-UDL test studied by (Pham et.al, 2017) which the initial crack was observed at the beams and the slab near the corner joint and the beam end regions. The validation of The FE analysis damage pattern result of the slab Top face and a side face of the primary beam (C-L and C-T beam) with the experiment done by (Pham et.al, 2017) is shown in Fig.9 a and b, respectively.



a) b)

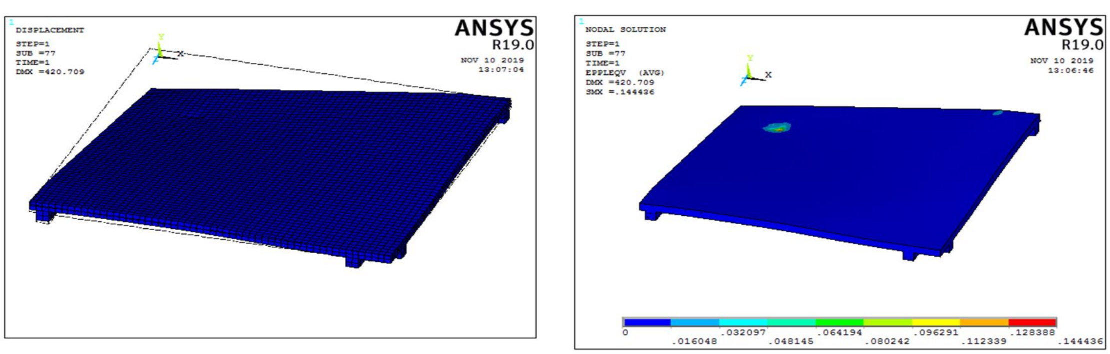
Fig.9 Top Surfaces Damage pattern a) Experiment investigations S-COR-UDL (Pham et.al, 2017)b) FE stimulation of S-COR-UDL

At the bottom slab soffit of the control specimen in the experimental test, The formation of parallel positive yield lines started occurring at about 40mm displacements (0.5 slab thickness) and progressively developed from the corner joint C-L-T column towards the slab center and also a complete diagonal line was formed at about 100mm displacements (1.25 slab depth) Fig.10a.The FE analysis Result Damage pattern on the bottom of the central slab in Fig.10b, which is the final damage pattern of the slab when the corner reach about displaced 400mm.



a) b)

Fig.10 Bottom Surfaces Damage pattern a) Experiment investigations S-COR-UDL *(Pham et.al, 2017)* b) FE stimulation of S-COR-UDL



a) b)

Fig.11.FE analysis result of a) General deformation and b) concrete spalling and crushing at the loading surface

IV. THE CONTROL SPECIMEN WITH ALL COLUMN INTACT

The investigation of load caring capacity of the control specimen without strengthening and with all column intact are done in FE using ANSYS 19 software. The FE analysis of Beam-Slab sub assemblage structure which supported by all four columns and changing the applied displacement at the center by assuming the Maximum deflection existed at the center of slab for uniform distributed load. This parametric used to interpret how much restore the load caring capacity of the corner column lost structure under CFRP strengthening. The modeling 3D schematic view, boundary and displacement loading position in Fig12.

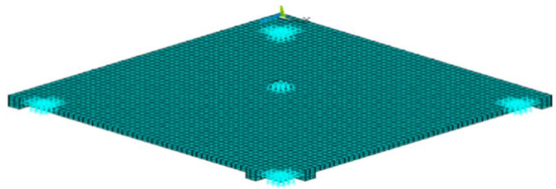


Fig.12 FEM schemes of control specimen with all columns intact

A. Discussions On Load Carrying Capacity Of The Control Specimen With All Column Intact

The investigation of load carrying capacity of Beam-Slab sub assemblage structure before losing the corner column are done using ANSYS 19 FE software. The load displacement analyses result in Fig.13 gives direction that how much the CFRP strengthening parameters are effective to restore the capacity when corner column lost suddenly and also it used to compare and contrast the peak load result between different ways of specimen strengthening.

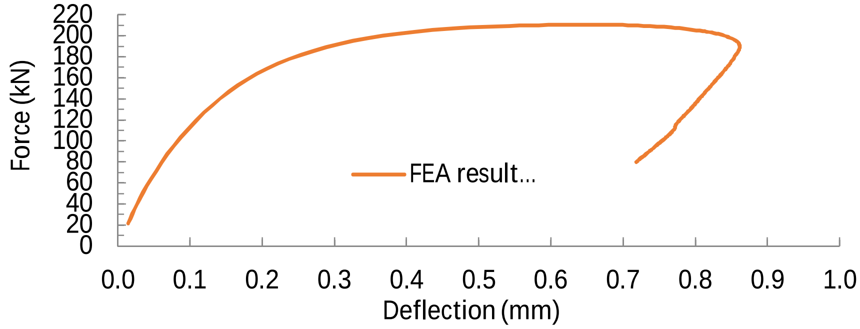


Fig.13 Load-displacement behavior of all column intact specimen

The FE result of maximum load carrying capacity of the control specimen with all column intact, at the maximum midpoint slab deflection is 210.62KN. however, in Fig.8 when the corner column suddenly removed the load carrying capacity lowered to 99.3KN which is decrease almost by 50%. in this study, investigate how to restore this capacity by CFRP strengthen mechanisms.

V. PARAMETRIC STUDIES AND RESULTS

A. Formulation of Parameter's

For this study the main target is restoration of strength in the load caring capacity of the system so that the fiber orientation constant for all parameter used 0^0 fiber orientation based on the study of fiber orientation effect in strength and ductility by (Sulaiman et.al, 2016). The span of specimen slab shows that the load transfer system is two-way so the parameters used in strengthening are the same way in the two directions.

The damage formed for distributed load test in the experiment shows that Slab and beam affected for different damage intensity level in Top, Bottom and side face of the slab-beam sub assemblage specimen. From this point of view, I would like to prepare the external layered CFRP parameters upper face or bottom face strengthening are best restoration the load caring capacity and also only beam or slab or combination of between them strengthening are best with different layer. The other one is in each parameter specified its total aria of CFRP used that implies the costs. The all strengthened parameters are consider equally in both direction since the structures have two-way load distributed systems.

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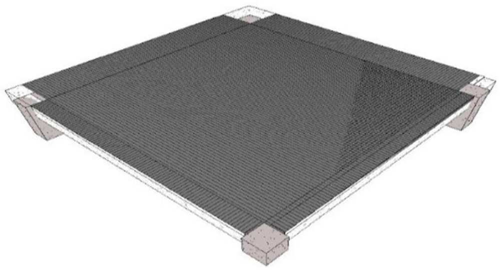
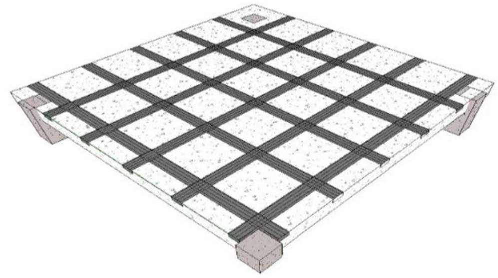
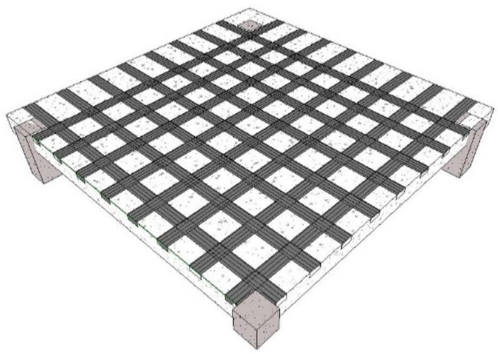


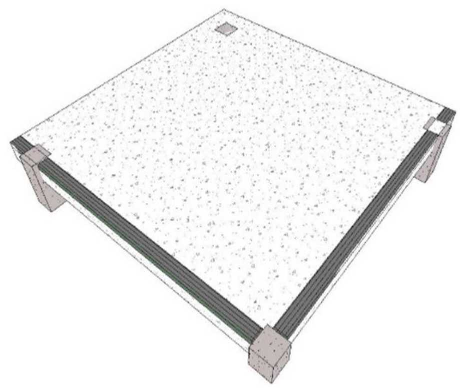
a) SAS



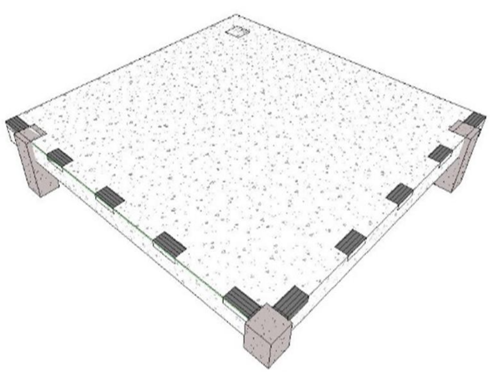
b) SPS



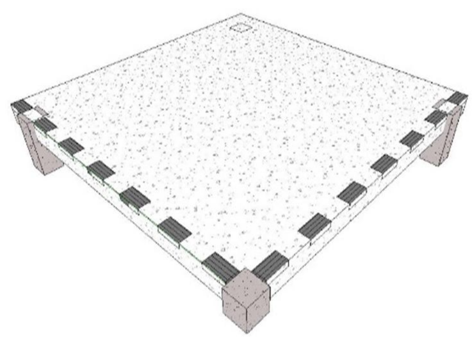
c)SPS-2



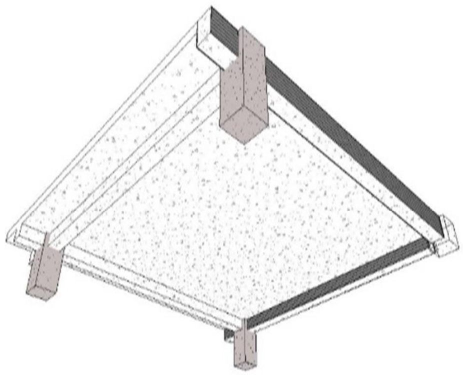
d) BAS



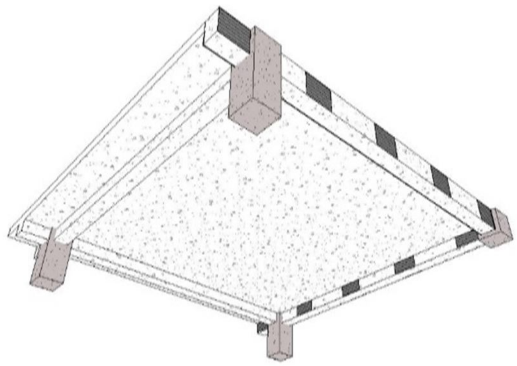
e) BPS-1



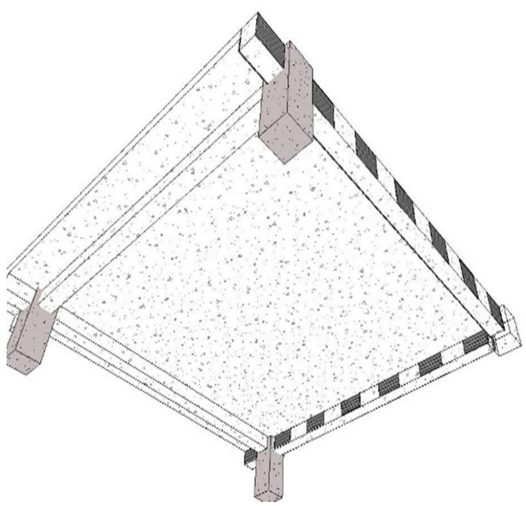
f) BPS-2



g) BSAS



h) BSPS-1



i)BSPS-2

Fig.14 Parametric specimens', a, b and c Slab Top, d, e & f Beam C-L&C-T Top and g, h & i Beam C-L&C-T external and internal strengthening schemes views

1) SAS Slab All Strength
2) SPS Slab Pattern Strength
3) BAS Beam All
4) BPS Beam Pattern strength
5) BSAS Beam Side All Strength
6) BSPS Beam Side Pattern Strength

Type	Location	Element	Orientation	Layer	Width of Strip (mm)	Spacing of Strip (mm)	Total Aria for single layer (m^2)	Remark
SAS	Top	Slab	0˚	2,4,6,8	2220	NO	12.1656	Fig.3.12 (a)
SPS-1	Top	Slab	0˚	2,4,6,8	100	400	2.74	Fig.3.12 (b)
SPS-2	Top	Slab	0˚	2,4,6,8	100	200	4.384	Fig.3.12 (c)
SAS	Bottom	Slab	0˚	2,4,6,8	2220	NO	12.1656	Mirror of Fig.3.12 (a)
SPS-1	Bottom	Slab	0˚	2,4,6,8	100	400	2.74	Mirror of Fig.3.12 (b)
SPS-2	Bottom	Slab	0˚	2,4,6,8	100	200	4.384	Mirror of Fig.3.12 (c)
BAS	Top	Beam	0˚	2,4,6,8	100	NO	0.44	Fig.3.12 (d)
BPS-1	Top	Beam	0˚	2,4,6,8	100	400	0.16	Fig.3.12 (e)
BPS-2	Top	Beam	0˚	2,4,6,8	100	200	0.24	Fig.3.12 (f)
BAS	Bottom	Beam	0˚	2,4,6,8	100	NO	0.44	Mirror of Fig.3.12 (d)
BPS-1	Bottom	Beam	0˚	2,4,6,8	100	400	0.16	Mirror of Fig.3.12 (e)
BPS-2	Bottom	Beam	0˚	2,4,6,8	100	200	0.24	Mirror of Fig.3.12 (f)
BSAS	Side	Beam	0˚	2,4,6,8	180	NO	4	Fig.3.12 (g)
BSPS-1	Side	Beam	0˚	2,4,6,8	180	400	1.44	Fig.3.12 (h)
BSPS-2	Side	Beam	0˚	2,4,6,8	180	200	2	Fig.3.12 (i)

Table 6 Summary of Considered parameters in the study

The others parameters in this study are by select the best scored in Beam element straightening which is from Top or Bottom strengthening and combined to Beam side strengthening and also select the best from slab element Top or Bottom strengthening and combined to the beam one. Finally, investigate the performance of the structure under this strength combination by increasing the layer numbers, the bond performance between CFRP and concrete material when the thickness of FRP increase study by (Agnus et.al, 2017).

The bonding between CFRP and Concrete Material is the main problem when the large number of CFRP Layer strengthening of reinforced concrete structure, since the thickness is increased when number of layers are increased. (Agnus et.al, 2017) study, the effect of increased FRP layer thickness on the bonding performance in the CFRP strengthening beams and he was obtained that a thickness of 1.5 mm gives the minimum contact stress and hence de-bonding will be less and also for thickness between 5mm to 10mm, the value of contact friction stress increases with increasing of the thickness of the FRP layer and also de-bonding between the concrete and CFRP materials are formed.

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B. Result And Discussions On Individual Structural Element Strengthening

1) CFRP strength of the Top surface

a) Case-1 Strength of Top Slab Surfaces

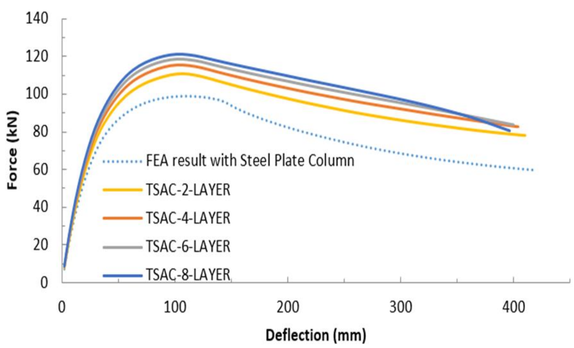

Fig.15 Load-displacement Results of the Top Slab All Cover (TSAC) strengthening's

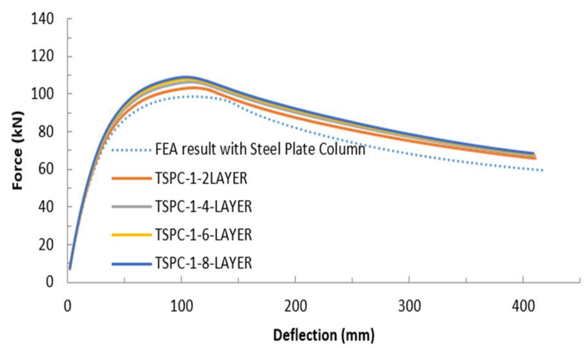

Fig.16 Load-displacement Results of the Top Slab Pattern-1 (TSPC-1) strengthening's

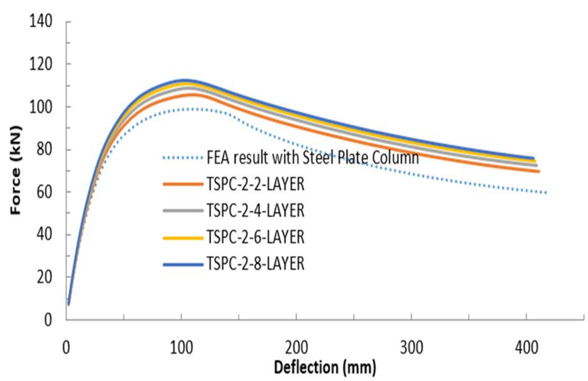

Fig.17 Load-displacement Results of the Top Slab Pattern-2 (TSPC-2) strengthening's

b) Case-2 Strength of the Top Beam surface

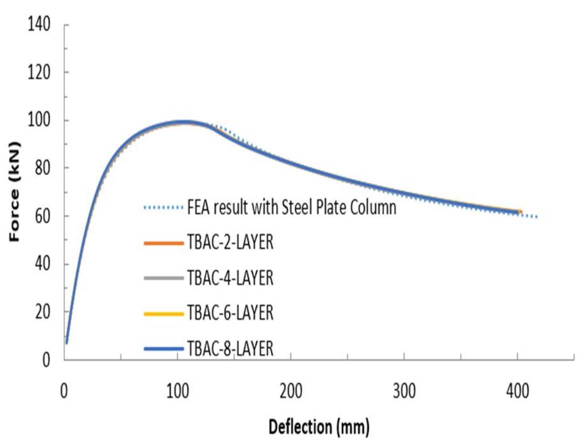

Fig.18 Load-displacement Results of the Top Beam All covers (TBAC) strengthening's

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In this case, the maximum peak load scored in Fig.18 at the eight layers is 99.2KN which is below the control specimen carrying capacity. The load displacement result in Fig.18 implies that the investigation of the second two strength parameters which is patterned cover strengthening is nonfunctional. so, by terminating this case and go to the second major parameters which disuse the effectiveness of the bottom surface strengthening. However, the peak load with corresponding aria consumed for All Top surfaces (TBAC) and the two types of pattern (TBPC-1 and TBPC-2) cover of C-L and C-T beams are described in Table.7.

2) CFRP strength of the Bottom surface

a) Case-1 Bottom Slab surface strength

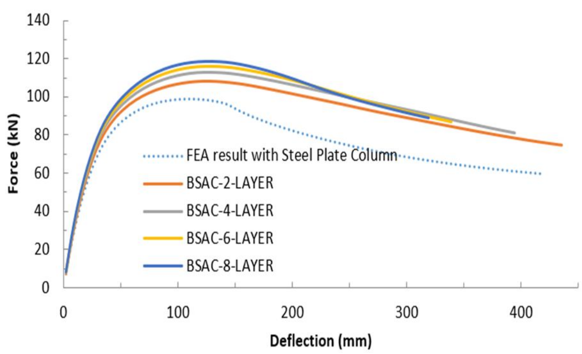

Fig.19 Load-displacement Results of the Bottom Slab All Cover (BSAC) strengthening's

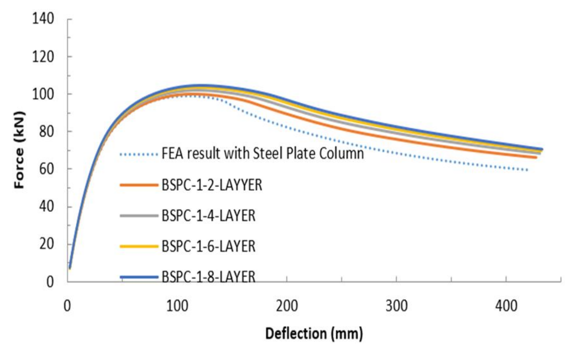

Fig.20 Load-displacement Results of the Bottom Slab Pattern-1 (BSPC-1) strengthening's

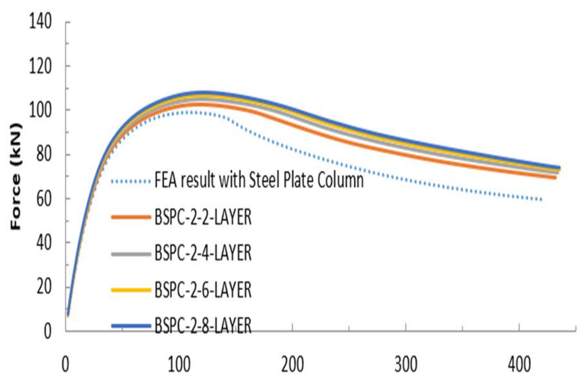

Fig.21 Load-displacement Results of the Bottom Slab Pattern-2 (BSPC-2) strengthening's

b) Case-2 Bottom Beam surface strength

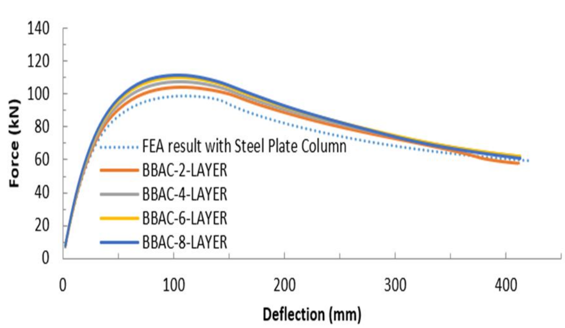

Fig.22 Load-displacement Results of the Bottom Beam All covers (BBAC) strengthening's

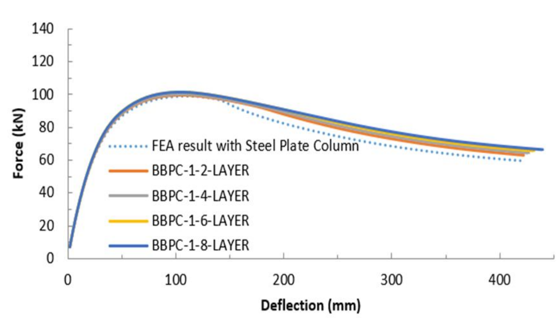

Fig.23 Load-displacement Results of the Bottom Beam Pattern-1 covers (BBPC-1) strengthening's

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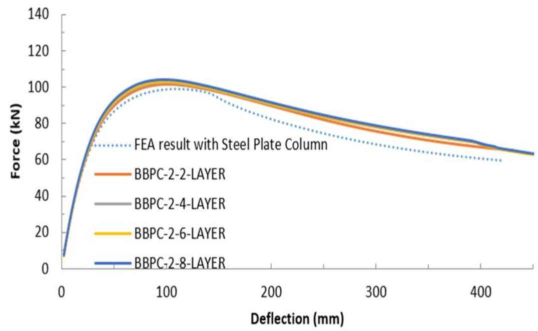

Fig.24 Load-displacement Results of the Bottom Beam Pattern-2 covers (BBPC-2) strengthening's

3) CFRP strength of the Beam Side surface

The two C-L and C-T primary beams are strength by CFRP in both internal and external sides. Like the Top and Bottom CFRP strength, Fig.14 shows that, the Beam side strength also consider the methodology of Side Beam All cover (SBAC) and pattern cover with 400mm and 200mm strip spacing (SBPC-1 and SBPC-2).

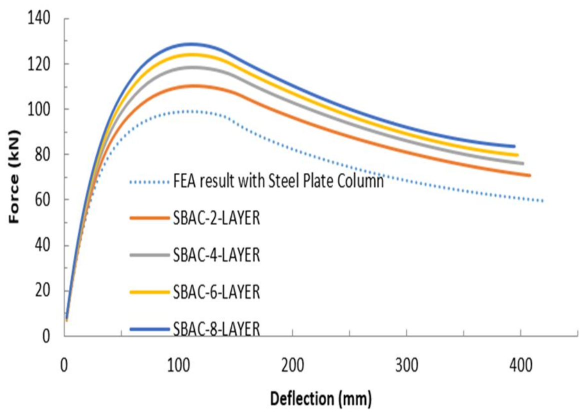

Fig.25 Load-displacement Results of the Side Beam All covers (SBAC) strengthening's

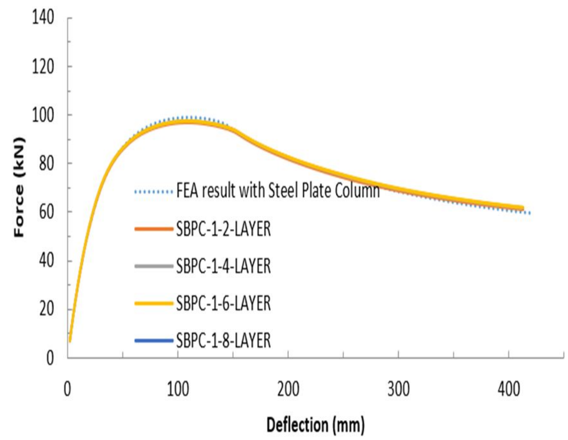

Fig.26 Load-displacement Results of the Side Beam Pattern-1 covers (SBPC-1) strengthening's

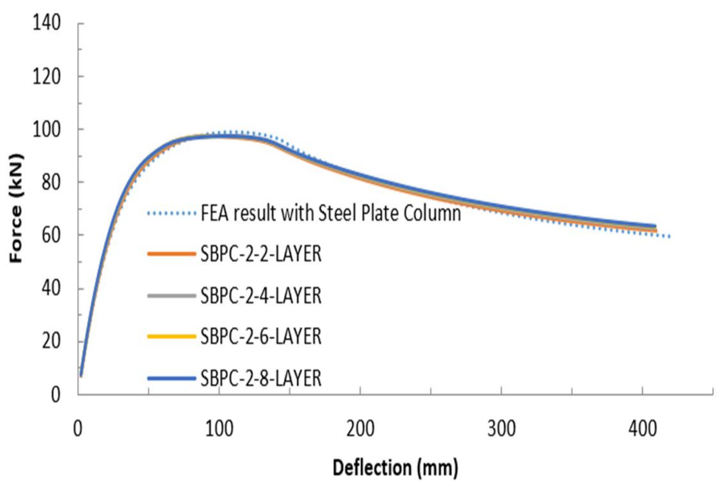

Fig.27 Load-displacement Results of the Side Beam Pattern-2 covers (SBPC-2) strengthening'

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Table.7 Summary of Peak Load Result and total aria of CFRP consumed for individual Structural element strength

Specimens'	Strengthening Methodology	Layers	Peak load (KN)			Displacement at the peak load(mm)			Residual Load (KN)			Displacement at the Residual Load(mm)			CFRP Aria (m^2)	CFRP Aria (m^2)
strengthening Location			Top	Bottom	Side	Top	Bottom	Side	Top	Bottom	Side	Top	Bottom	Side	Top=Bottom	Side
Control specimen	No	No	99.3			97			59.7			420.11			No	
Strengthening of Slab	All cover	2	110.9	108.36		100.68	127.37		78.11	74.91		410.36	435.68		48.60	
		4	115.28	112.76		101.5	128.62		82.5	81.04		404.05	394.59		97.30	
		6	118.33	116.03		101.48	129.3		83.6	86.52		399.83	338.83		145.98	
		8	120.86	118.72		106.7	129.75		80.398	89.06		396.4	319.19		194.60	
	Pattern-1,400mm spacing stripes	2	103.54	100.1		111.46	112.95		65.99	66.273		411.01	427.31		10.96	
		4	106.27	102.16		106.11	119.39		67.1	68.53		410.23	430.59		21.92	
		6	107.98	103.58		106.22	119.87		67.94	69.74		409.28	431.94		32.88	
		8	109.12	104.65		106.29	120.23		68.54	70.54		408.62	432.58		43.84	
	Pattern-2,200mm spacing stripes	2	105.57	102.68		111.78	119.59		69.62	69.55		410.46	431.84		17.52	
		4	108.85	105.15		106.48	120.56		72.63	71.85		408.98	434.38		35.04	
		6	110.79	106.73		106.63	121.51		74.52	73.1		407.54	435.19		52.56	
		8	**111.74**	107.89		**112.16**	121.56		**75.76**	73.81		**406.21**	435.49		**70.08**	
Strengthening of Beam	All cover	2	98.76	108.36	110.42	105.49	127.38	111.57	61.65	74.91	70.94	403.29	435.68	407.97	1.76	8
		4	99.02	112.76	118.24	110.78	128.63	111.32	61.6	81.04	75.92	401.26	394.59	401.77	3.52	16
		6	99.13	116.02	124.02	110.64	129.3	111.04	61.51	86.85	79.79	400.34	338.83	397.36	5.28	24
		8	99.2	**118.71**	**128.64**	110.54	**129.75**	**110.75**	61.44	**89.06**	**83.53**	399.78	**319.19**	**394.25**	**7.04**	**32**
	Pattern-1,400mm spacing stripes	2	–	100.1	–	–	112.95	–	–	66.27	–	–	427.13	–	0.64	2.88
		4	–	102.16	–	–	119.39	–	–	68.53	–	–	430.53	–	1.28	5.76
		6	–	103.58	–	–	119.872	–	–	69.74	–	–	431.94	–	1.92	8.64
		8	–	104.65	–	–	120.23	–	–	70.54	–	–	432.58	–	2.56	11.57
	Pattern-2,200mm spacing stripes	2	–	101.4	–	–	100.98	–	–	65.02	–	–	430.65	–	0.96	4
		4	–	102.53	–	–	101.26	–	–	65.84	–	–	418.14	–	1.92	8
		6	–	103.29	–	–	95.71	–	–	63.13	–	–	449.55	–	2.88	12
		8	–	103.9	–	–	95.82	–	–	63.11	–	–	450.51	–	3.84	16

C. Result And Discussions On Combined Structural Element Strengthening

The individual element strengthening result in Table.7, the side all cover of the two C-L and C-T beams are scored the maximum load which is 128. 64KN. however, before the corner column lost the structures has 210.62KN, so the side strengthening of the two beams restore only 61.07%. The next parameter discusses how to increase this percentage by combining that individual structure element strengthening like Beam Bottom and side, Beam side with Slab Top or combined with Beam Side and Bottom with slab Top.

The selection of the strengthening type from the Top All cover or Pattern cover and the Bottom All cover or Pattern cover is based on the scored of its peak load. For instance, from slab Top or Bottom strength, the Top one scored peak load of 120.86KN in the case of Top slab All cover (TSAC-8-Layer) by consuming total CFRP area of 194.60m2. However, the Top Slab pattern-2 strength (TSPC-2-8-Layer) by used up the total CFRP area of 70.8m2 it scored 111.74KN which is a small difference than that of the Top slab All cover (TSAC-8-Layer) but it is effective with respect to a total CFRP area consumption, based on this criteria The Top Slab Pattern-2 Cover (TSPC-2) is the selected one from top slab CFRP cover strengthening and also from the two C-L and C-T beams strength, the Bottom beam All coverages (BBAC) and The Side Beam All cover (SBAC) are selected based on its peak load scored. The total area consumed in this case is the summation of the row in the Table7 at the respective parameters which also mentioned in Table8.

1) Case-1 Bottom and Side Beam surface strength

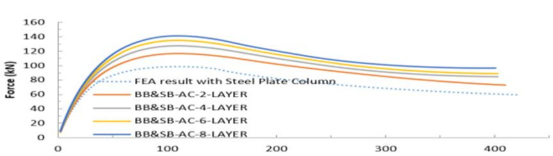

Fig.29 Load-displacement Results of the Side Beams All covers with The Top Slab Pattern-2 cover (BSAC&TSPC-2) strengthening's

2) Case-2 Beam Side and Top Slab surface strength

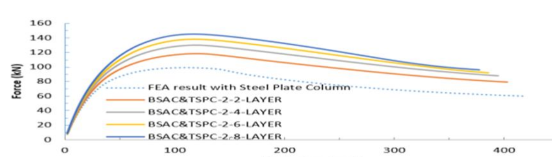

Fig.28 Load-displacement Results of the Bottom and Side Beam All covers (BB&SBAC) strengthening's

3) Case-3 Side and Bottom Beam with Top Slab surface strength

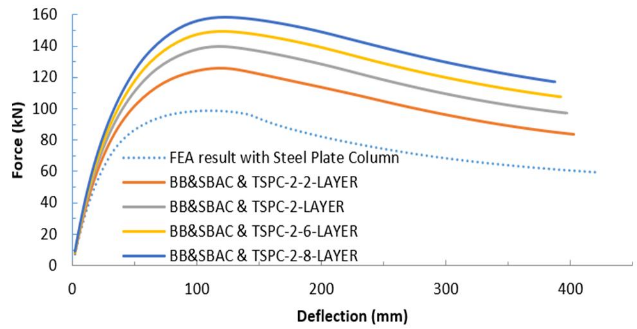

Fig.30 Load-displacement Results of the Side & Bottom Beams All covers with The Top Slab Pattern-2 cover (BB&SBAC with TSPC-2) strengthening's

Table.8 Summary of Peak load for Combination Structural element strengthening

Specimens'	strengthening Methodology	Layers	Peak load (KN)	Displacement at the peak load(mm)	Residual Load (KN)	Displacement at the Residual Load(mm)	CFRP Aria (m^2)
Control	No	No	99.3	97	59.7	420.11	No
Combination of Beam Bottom and Side	All cover	2	117.07	111.57	73.08	409.45	9.76
		4	127.43	111.17	118.83	164.17	19.52
		6	135.13	110.84	88.93	402.44	29.28
		8	**141.46**	**110.59**	**96.62**	**4007.78**	**39.04**
Combination of Beam Side and Slab Top	All cover Beam side & Pattern-2 Top slab	2	118.65	117.22	79.43	402.64	25.52
		4	130.17	117.19	87.91	394.56	51.04
		6	138.54	117.07	92.33	358.59	76.56
		8	**145.23**	**116.9**	**96.02**	**377.26**	**102.08**
Combination of Beam Side & Bottom and Slab Top	All cover Beam side&Bottom & Pattern-2 Top slab	2	125.72	117.26	83.53	402.64	27.28
		4	139.42	117.19	96.93	397.13	54.56
		6	149.55	122.5	107.78	392.48	81.84
		8	**158.06**	**122.45**	**116.92**	**387.34**	**109.12**

D. CFRP Strength Of Combined Structure Element With Higher Numbers Of Layers

The maximum thickness for 8-layer CFRP having 0.334mm thickness of a single layer gives us a total of 2.664mm, which is the insignificant thickness to affect the bond between them. Still giving us a chance to increase the layer according to (Agnus et.al, 2017) which study the effect of CFRP thickness on bonding performance, and by increasing the number of CFRP layer to 16 which is 5.328mm thickness, the performance and load carrying capacity of the structure is investigated.

The case selected for strengthening the structural system, the one that combines CFRP strength of C-L and C-T beams at the bottom and side and by covering all area of the Top Slab with Pattern-2 CFRP arrangement Strengthening scenario gives the highest load carrying capacity from all cases.

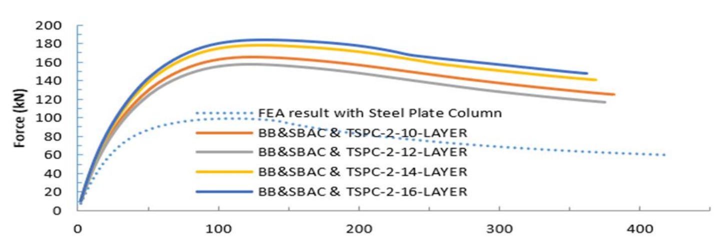

Fig.31 Load-displacement Results of higher number of layer Side & Bottom Beams All covers with The Top Slab Pattern-2 cover (BB&SBAC with TSPC-2) strengthening's

Table.9 Summary of Peak load for Combination Structural element strengthening with higher number of layers

Specimens'	strengthening Methodology	Layers	Peak load (KN)	Displacement at the peak load(mm)	Residual Load (KN)	Displacement at the Residual Load(mm)	CFRP Aria (m^2)
Control	No	No	99.3	97	59.7	420.11	No
Combination of Beam Side & Bottom and Slab Top	All cover Beam side&Bottom & Pattern-2 Top slab	10	165.43	122.4	125.02	381.47	136.48
		12	168.78	169.81	133.1	375.04	163.68
		14	178.22	132.88	140.8	368.371	191.07
		16	**184.01**	**132.78**	**147.78**	**361.82**	**218.37**

The load displacement result in Fig.31 shows that, the combined external laminated CFRP strength of the two C-L and C-T Beams with the top slab part at the 16-Layers scored better restoration of the load caring capacity performance. the load carry capacity of the Beam-Slab sub assemblage structure before losing corner column is 210.65KN. however, after losing this column the capacity is lowered to 99.3KN but 87.36% of the performance, which is capacity of 184.01KN is restored by strength the Beam and slab structural element using external laminated 16-Layer CFRP material.

VI. SUMMARY AND CONCLUSION

A. The modeling and loading methodology in ANSYS Mechanical APDL 19 give good approximate solution to the Experiment. The peak load in the experiment was 102.9KN and in the FE analysis the peak load is 99.3KN which is -3.47% error and also have nearest damage profiles at the top and bottom of Slab and Beam and at the side of the Beams.

B. the load carrying capacity of the structure under disturbed load which the control specimen with all column intact was 210.62KN and after losing the corner column the load capacity lowered to 99.3KN which is 50% of the structural stiffness and visible damages shown in many places at the structure elements which is in the beam and slab.

This study evaluates CFRP strengthening cases that could be efficient on strengthening. The evaluation assesses the peak load carrying capacity of a section at different layers with different arrangement of CFRP, including covering all the structural area, Pattern cover with a wide strip spacing or narrower strip spacing that could be effective on strengthening with their corresponding consumption of area of CFRP. The evaluation of the different cases is described below

1) The strengthening of the slab structural element at the Top or Bottom part; the Top part strengthened are more effective than the Bottom one for all cover and pattern cover scenario. The maximum load caring capacity is obtained in the case of all the Top part of slab is covered having a magnitude of 120.86KN at eighth layer with 21.7% increment than a control specimen. However, the peak load carrying capacity is obtained with the total area of CFRP of 194.60m2, but in the case of Pattern-2 arrangement case the peak load carrying capacity at the eighth layer is 111.74KN with 70.08m2 total area of CFRP material, so according to this the Pattern-2 strengthening scenario are more effective as far as strength and economy concerns.

2) The External and Internal side strength of C-L and C-T Beams element are more effective on enhancing the Peak Load carrying capacity and usage of total area of CFRP material than Beams Bottom, Top and also Slab element strengthening. At the eight-layer covering all the sides of the beam gives a capacity of 128.64KN with 29.54% increment than control specimen and also consumes only 32m^2 of total CFRP area.

3) The combined strength of the beam element with slab element gives better performance however it consumes more areas of CFRP material. The External, internal side and bottom all cover strength of C-L and C-T Beams with the Top Pattern-2 Cover strength of the slab element at the eight layer gives peak load carrying capacity of 158.96KN which has an incremental of 59.18% than the control specimen and uses a total CFRP material area of 109.12m^2 is consumed.

4) By increasing the number of layers into double (16 Layer) in the combined structural element CFRP strength of the C-L and C-T Beams at bottom and side surface with the Top Slab surface, the peak load carrying capacity increased to 184.01KN which means 85.30% increment from control spaceman.

5) The load carry capacity of the Beam-Slab sub assemblage structure before losing corner column is 210.65KN. However, after losing this column the capacity is lowered to 99.3KN. And 87.36% of the performance, with a capacity of 184.01KN is restored by strengthening the beam and slab structural element using external laminated 16-Layer CFRP material.

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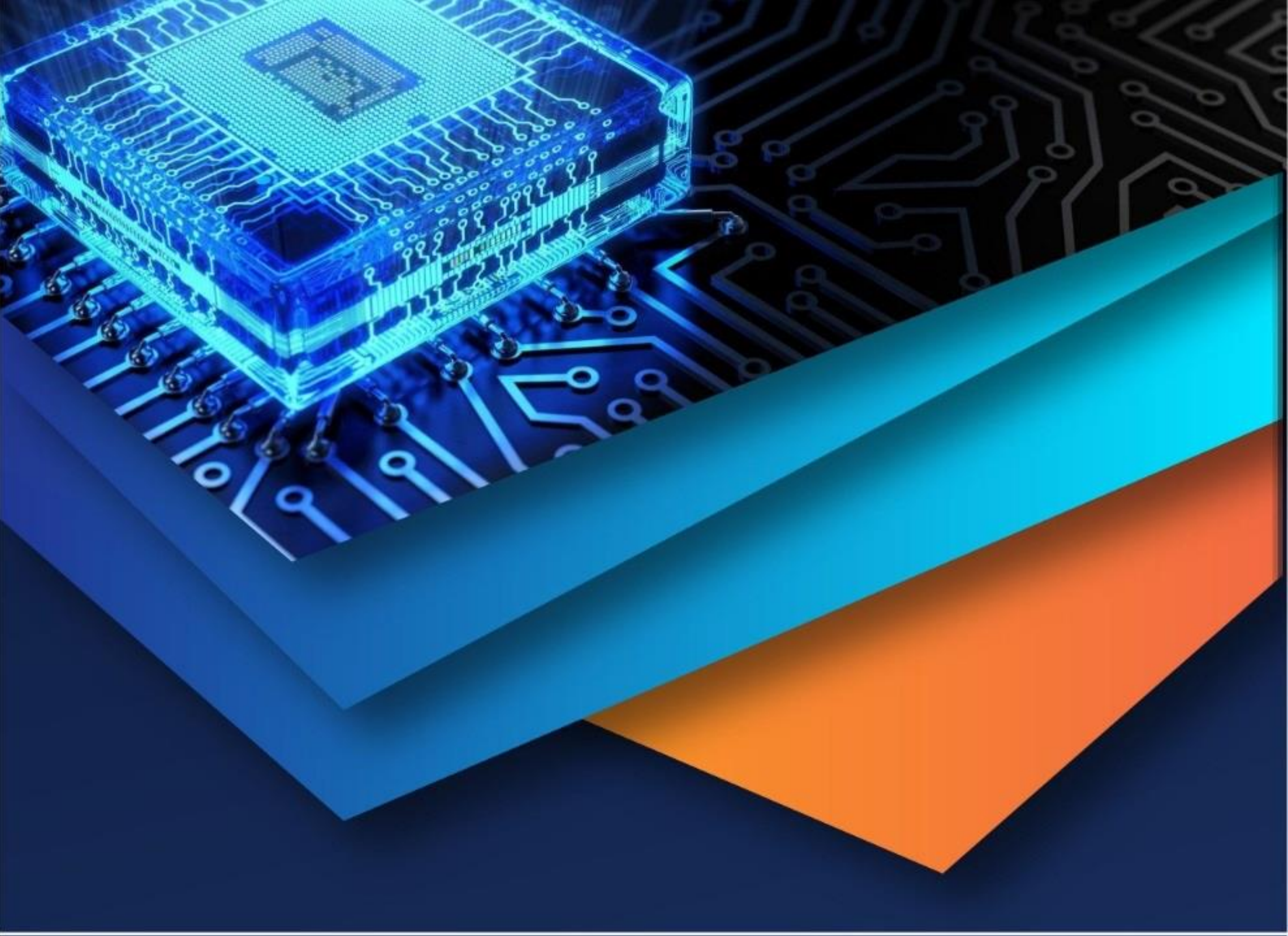

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