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# DEFINING SEQUENTIAL CONSTRUCTION ANALYSIS FOR BUILDINGS IN ETABS 2016 AND SAP2000 V19

# I. Overview

Since the past, multi-storey building frames have been analyzed in a single step as a complete frame with all the loads acting on the building namely self-weight, super-imposed dead loads, live loads, and the lateral loads being applied on the frame at a given instant when the construction of the whole frame is completed. In actual, the dead load due to each structural components and finishing items are imposed in separate stages as the structures are constructed storey by storey.

The performance of a structure with the various loads applied in a single step differs significantly from that when the loads are applied in stages. Hence, in order to simulate the actual condition during the construction of the frame, the frame should be analyzed at every construction stage taking into account variation of loads. The phenomenon known as Sequential Construction Analysis is used to analyze the structure at each storey.

Sequential construction analysis is a nonlinear static analysis which takes into account the concept of incremental loading. Buildings with transfer beams or transfer slabs are vulnerable to the effect of sequential construction this is because when sequential construction is ignored, the analysis assumes that the entire loads are carried by the entire structure, i.e. vierendeel truss action. Sequential construction is also important on analysis of high rise buildings where creep and shrinkage must be considered.

Sequential construction in ETABS 2016 and SAP2000 v19 allows you to easily define a sequence of stages wherein you can add or remove portions of the structure, selectively apply load to portions of the structure. The sequence of stages can be matched on how the building will be built. Time-dependent material behavior such as aging, creep, and shrinkage can also be considered.

This technical note discusses on how to use the built-in Nonlinear Staged Construction Analysis (Autogenerated or Manual) in ETABS 2016 / SAP2000 v19. This technical note will also briefly show the difference on the results between a normal linear elastic analysis and sequential construction analysis.



# II. Activating Auto Generated Staged Construction Analysis

ETABS 2016 and SAP2000 v19 has built-in Auto Construction Sequence tool that can be used to account for sequential construction effect.

Click on to **Define>Auto Construction Sequence Case...** tick "Case is Active" in the dialogue box that will appear.

TAuto Construction Sequence Load Case X	
General   ✓ Case is Active   Auto Construction Sequence Load Case Name   Geometric Nonlinearity Option   P-Delta   Construction Sequence   Combine this number of Stories in each Construction Sequence Group   Exclude this Group Until the Last Step   Loads Applied   Load Pattern Name Scale Factor   Add   Delete	P-delta effect can also be considered. specify the number of stories to be combined in each construction stage
Design Combinations ☑ Replace Dead Type Load Cases with this Load Case in all Default Design Combinations OK Cancel	Dead Loads, and part of Live Loads (optional) can be considered. Specifying Dead Load only assumes that all other loadings will be imposed on the structure after the whole structure is constructed.

Loads to be applied are typically the Dead Loads, and part of Live Loads (optional).

A new Auto Nonlinear Static Staged Construction load case will be generated. This load case cannot be modified.

d Cases				Click to:
Load Case Name	Load Case Type	^		Add New Case
Wx	Linear Static			Add Copy of Case
Wy	Linear Static			Modify/Show Case
EQx	Linear Static			Delete Case
EQy	Linear Static	1	:	
RSA	Response Spectrum			Show Load Case Tree
AutoSeq	Auto Nonlinear Static Staged Construction		1	
Buck 1-1-NL	Buckling			
Buck 1-2-NL	Buckling			ОК
Buck 1-3-NI	Buckling			

In the generated Auto Nonlinear Static Staged Construction load case, the number of stages and number of operations on each stage corresponds to the grouping of stories specified in the Auto Sequential Construction setting.



G	ieneral								
G	Load Case	Name			AutoSeq			Design	
	Load Case	Type			Nonlinear Sta	aged Construction	~	Notes	
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	Number	Stage	Name	Duration, Days	Output	User Comment	Operations		
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	2	2		0	No		2	Add Copy	
	4	4		0	No		2	Insert	
	5	5		0	No		2	Delete	
	6	6		0	No		2		
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Click here to <sub>o</sub> view the different	ther Parame Geometric	ters Nonlinearity O	ption		P-Delta		~		
operations	Results Sa	ived	End of Ea	ch Stage		Modify	/Show		
performed on	Nonlinear	Parameters	Default			Modify	/Show		
each stage.				OK		Cancel			
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Looking at the above operation, the program's first operation is to add structure, and then followed by operation to load the objects that has just been added with the Dead Load pattern with scale factor of 1 just as previously specified. The operation for all the stages can also be viewed using the "Tree View" button.

	Right Click Tree for Optio
ADD Structure: Group = ~Story1	
LOAD Objects if Added: Group = ~Story1; Load Type = LOAD; Load Name = Dead; Scale Factor = 1	
A STAGE 2	
ADD Structure: Group = ~Story2	
LOAD Objects if Added: Group = ~ Story2: Load Type = LOAD: Load Name = Dead: Scale Factor = 1	
- A STAGE 3	
ADD Structure: Group = ~Story3	
LOAD Objects if Added: Group = ~Story3; Load Type = LOAD; Load Name = Dead; Scale Factor = 1	
- A STAGE 4	
ADD Structure: Group = ~Story4	
LOAD Objects if Added: Group = "Story4; Load Type = LOAD; Load Name = Dead; Scale Factor = 1	
- A STAGE 5	
ADD Structure: Group = ~Story5	
LOAD Objects if Added: Group = ~Story5: Load Type = LOAD: Load Name = Dead: Scale Factor = 1	
- A STAGE 6	
W ADD Structure: Group = ~ Story6	
V LOAD Objects if Added: Group = ~ Story6: Load Type = LOAD: Load Name = Dead: Scale Factor = 1	



A sequential construction load case can also be added manually in ETABS 2016 and SAP2000 v19.

Click on to **Define>Load Cases...** add a new load case and select "Nonlinear Staged Construction" as Load Case Type.

Load Case	e Name		SeqConst-Ma	anual		Design
Load Case	е Туре	(	Nonlinear St	aged Construction	~	Notes
Exclude 0	bjects in this Group		Not Applicat	ole		
Mass Source			Previous			
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Zero Ir	nitial Conditions - Start fro	m Unstressed St	ate			
O Contin	ue from State at End of N	Vonlinear Case (	Loads at End	of Case ARE Included	)	
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itage Definiti	ion					
Stage	Stage Name	Duration,	Provide	User Comment	Number	
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Stage	Operations	Tree V	iew	Auto F	Rename	
ther Parame	eters					
Geometric	Nonlinearity Option	C	P-Delta		$\sim$	
Results Sa	aved End of	Final Stage Only		Modify/	Show	
	Parameters Default			Modify/	Show	

Operation	Object Type	Object Name 🖌	Age at Add, days	Туре	Name	Scale Factor	
Add Structure	Group	Group1	0				Add
Load Objects If Added	Group	Group1		Load Pattern	Dead	1	
Bemove Structure	Group	Temporary Support					Add Cop
Load Objects If Added Load Objects Change Sections							
		Stage Name: Stage1	~	Stage: 1	of 1		

# III. Linear Elastic Analysis vs. Sequential Analysis

A 6-storey model below has been analyzed for both Linear Elastic Analysis and Sequential Construction Analysis for dead load case. The 6-storey model involves a transfer beam at Storey 1 along gridline 1.

Two different cases were also considered: (1) all beams with same size; and (2) the transfer beam has bigger size.

(Case 1) All the beams, including the transfer beam, have the same size of 600(D) x 300(W).



Axial force on the column that is supported by the transfer beam:

The axial force on the column from Sequential Construction Analysis is about (10) times larger than in Linear Elastic Analysis.

B. Bending moment on transfer beam:





The bending moment on the transfer beam from Sequential Construction Analysis is about (3) times larger than in Linear Elastic Analysis.

# C. Displacement:



The midspan displacement on the transfer beam from Sequential Construction Analysis is about (2.5) times larger than in Linear Elastic Analysis. In contrast, the displacement on top of columns are smaller Sequential Construction Analysis. This is because in Sequential Construction Analysis, the bottom of the columns of the next stage is inserted at the undeformed state of that joint and neglecting the joint displacements from the lower floors as it is assumed that the floor will leveled prior to construction of the next floor.

(Case 2) The transfer beam is enlarged to  $900(D) \times 300(W)$ , all other beams have the same size of  $600(D) \times 300(W)$ .



Axial force on the column that is supported by the transfer beam:



The axial force on the column from Sequential Construction Analysis is still about (3) times larger than in Linear Elastic Analysis.



### B. Bending moment on transfer beam:

The bending moment on the transfer beam from Sequential Construction Analysis is about (2) times larger than in Linear Elastic Analysis.

#### C. Displacement:



The midspan displacement on the transfer beam from Sequential Construction Analysis is about (2) times larger than in Linear Elastic Analysis.



The result from the two cases above shows the sensitiveness of sequential construction effects on transfer structures and thus should not be neglected.