Analysis of Reinforced Concrete Structures Subjected to Blast Loading

S. Karapinar, I. Sanri, G. Altay

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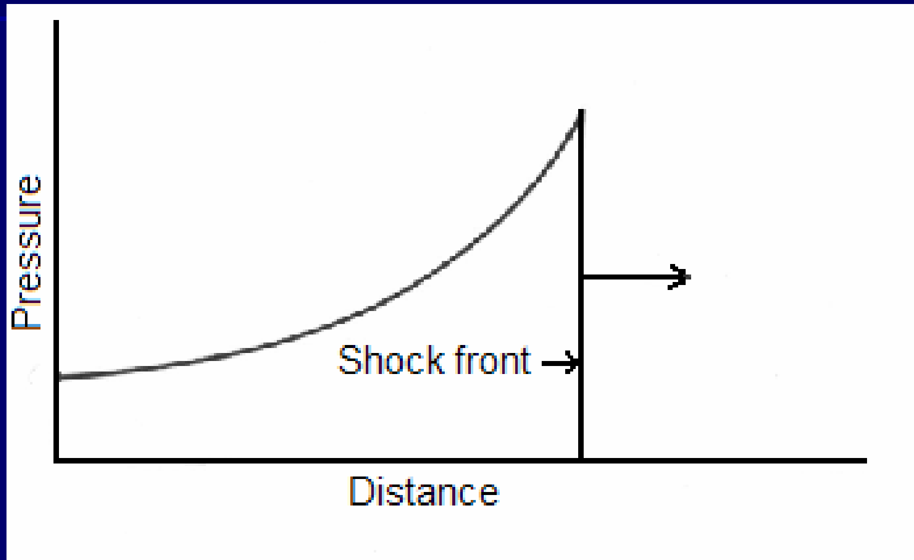
Aim of the Study

- Analyze the structures under the effects of blast loading.
- Including; the threat definition, blast wave parameters, dynamic properties of materials and damage assessment.

Definition of Blast Loading

- Blast loading may result from the detonation of high explosives, chemical ammunitions.
- Type of extraordinary dynamic load and it has to be described by two parameters; peak overpressure and duration.
- Blast loading is a function of : Distance of the structure from the explosion, and the charge weight or a weapon size.

Formation of a Blast Wave



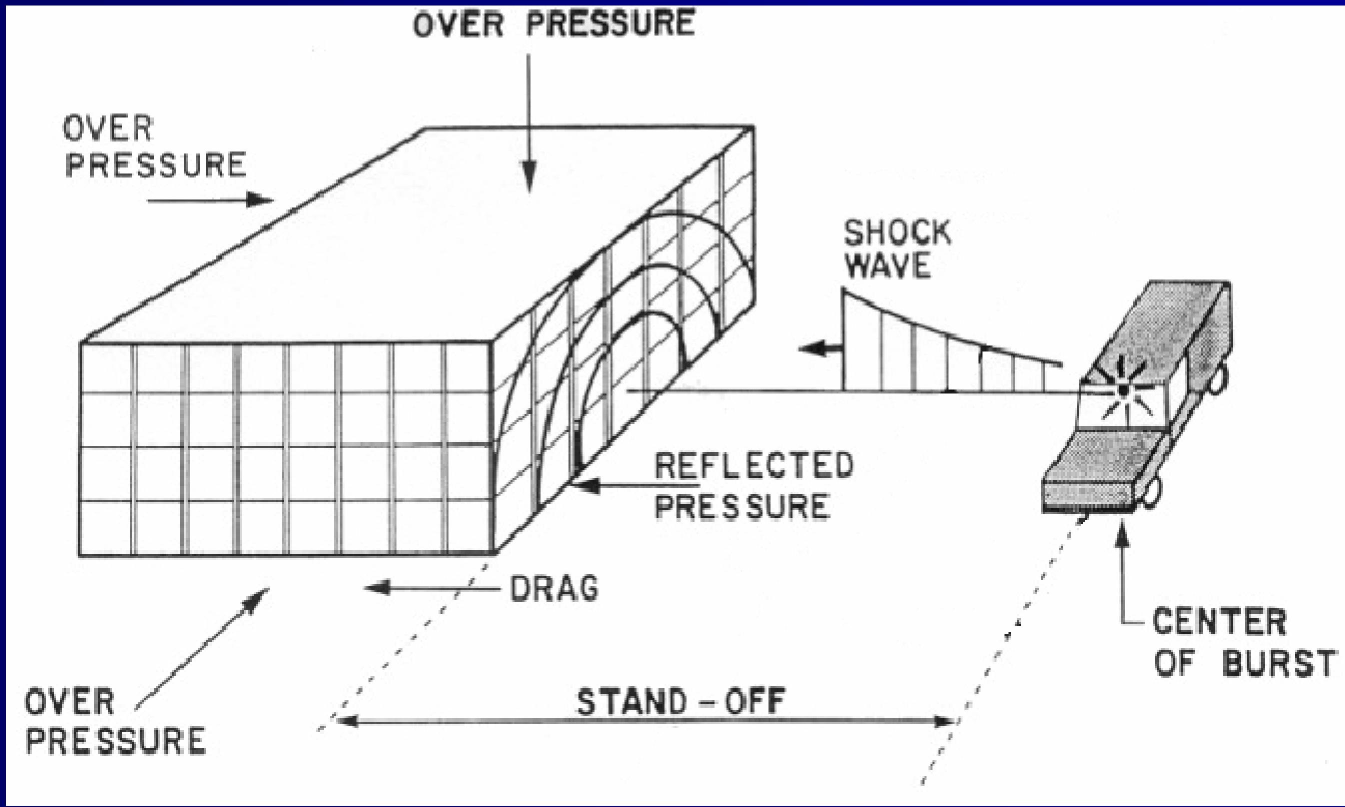
Variation of pressure within a shock wave (Fertis,1973, Dynamics And Vibration Of Structures)

Threat Definition

- *Charge Weight or weapon size (W) :* W is expressed in weight or mass of TNT ; the equivalent W of any other explosive material is based on experimentally determined factors or the ratio of its heat of detonation to that of TNT.

- *Stand-off Distances (R) :* R measures how close to the building a bomb could explode and is therefore a function of the physical characteristics of the surrounding site.

General Overview of Blast Loading

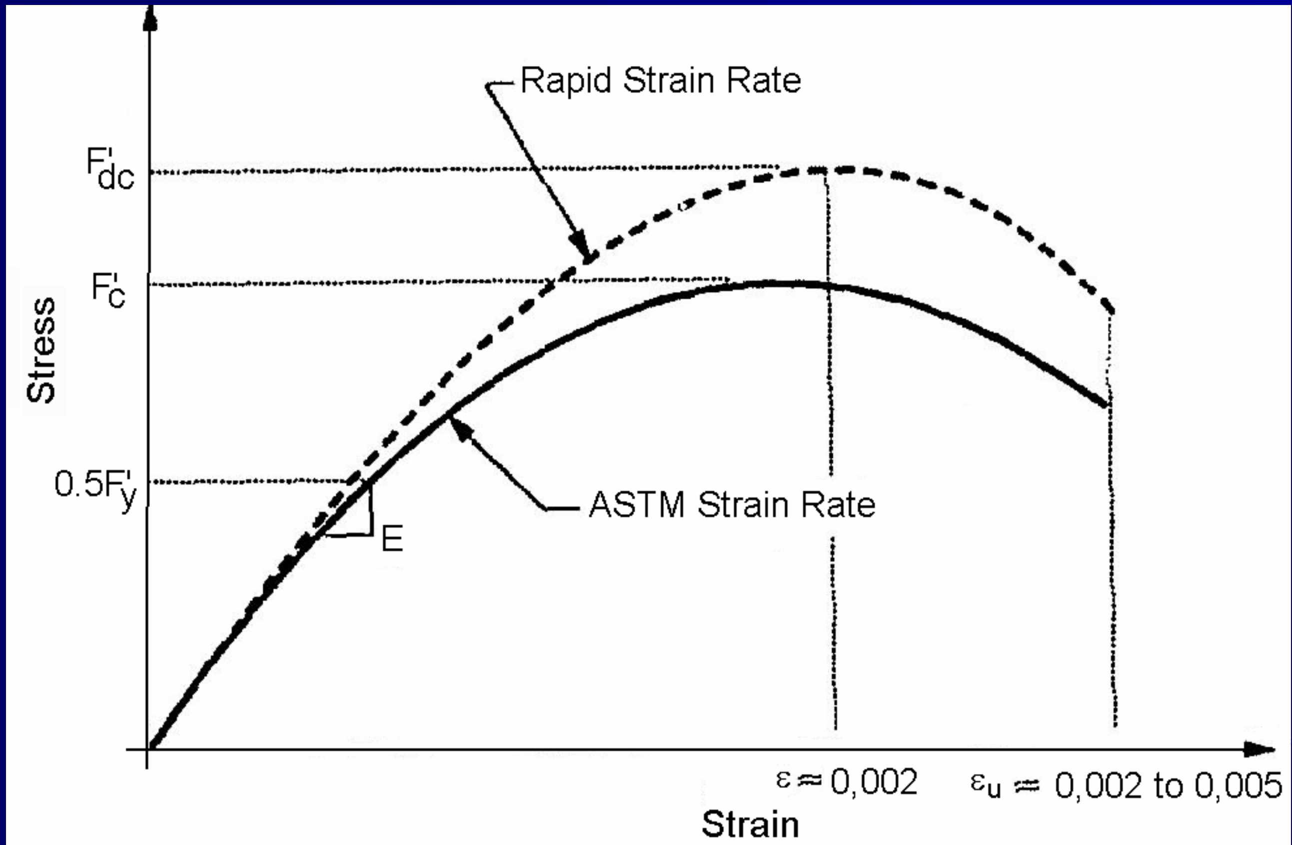


Dynamic Behaviour of Material Under Blast Loading

When the concrete is strained;

- The resistance increases linearly with deflection until the reinforcing bars yield.
- The deflection is increasing but the resistant remains constant until at a deflection corresponding to a support rotation of 2°
- At a deflection corresponding to a value of about 4° the element will lose its structural integrity and fail.

Dynamic Strength Increase



Effects of strain rate on stress-strain curve for concrete (Ref: TM 5-1300)

Dynamic Increase Factor (DIF)

DIF is equal to the ratio of the dynamic material strength to static strength.

DIF is a function of;

- Static material strength : If the static strength of material is high then the increase in dynamic strength will be low.
- Strain rate : If the material is strained rapidly then the increase in dynamic strength will be high.

Deformation Limits

The controlling criteria in the blast-resistant design is a limit on the deformation or deflection of element.

Two methods for evaluation of structural response :

- Ductility ratio
- Support rotation

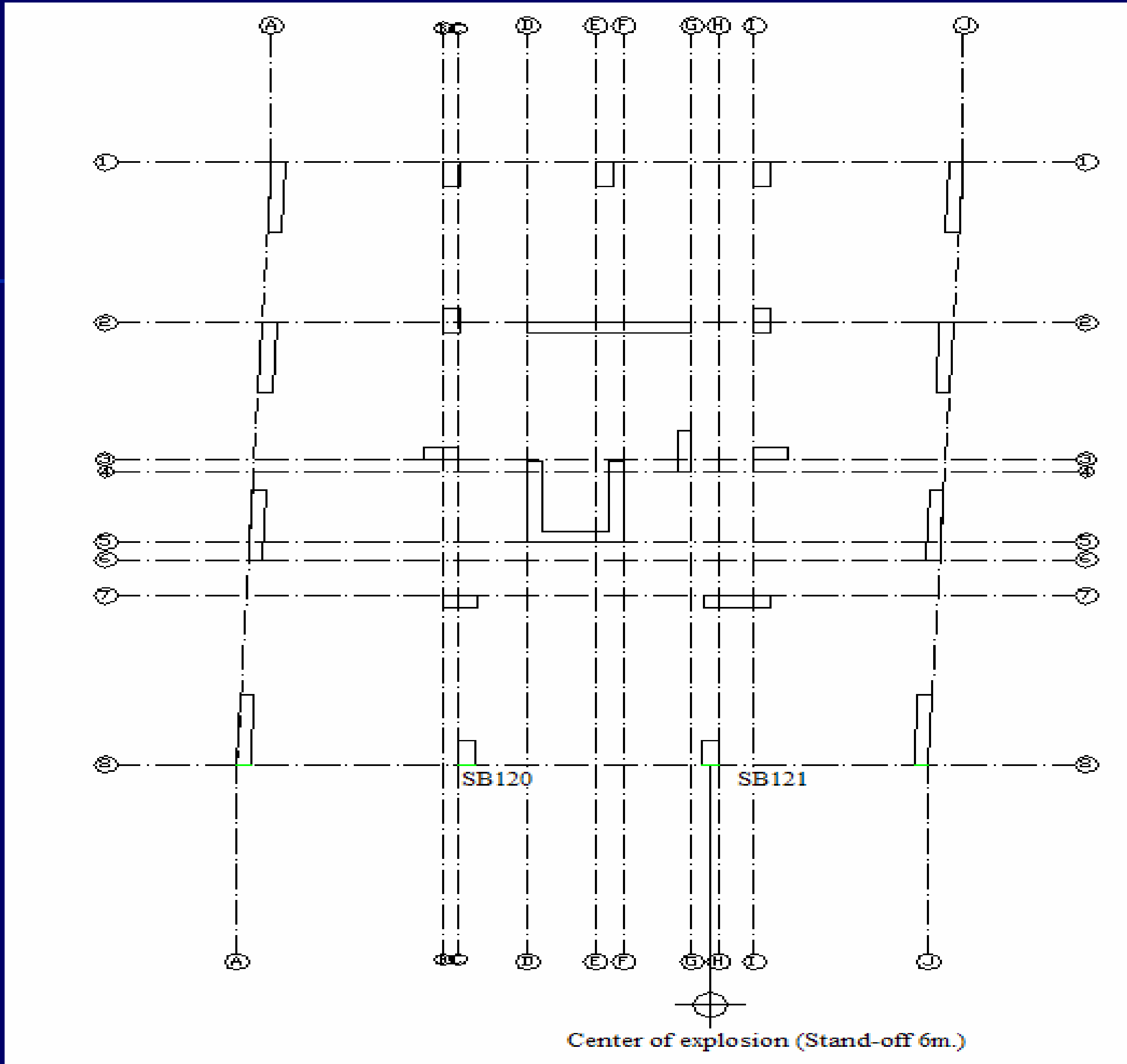
Case Study

- The analysis of the structural elements under blast loading with a given charge weight and stand-off distance.
- The investigation of the damaged system which contains the analysis of the system with member removed according to the explosions.

Analysis of Structure under Blast Loading

- Charge weights are 500 kg , 750 kg , 1000 kg and 1500 kg of TNT.

- Stand-off distance is considered as 6m. which is the closest point to the building according to the plan configuration of the building.



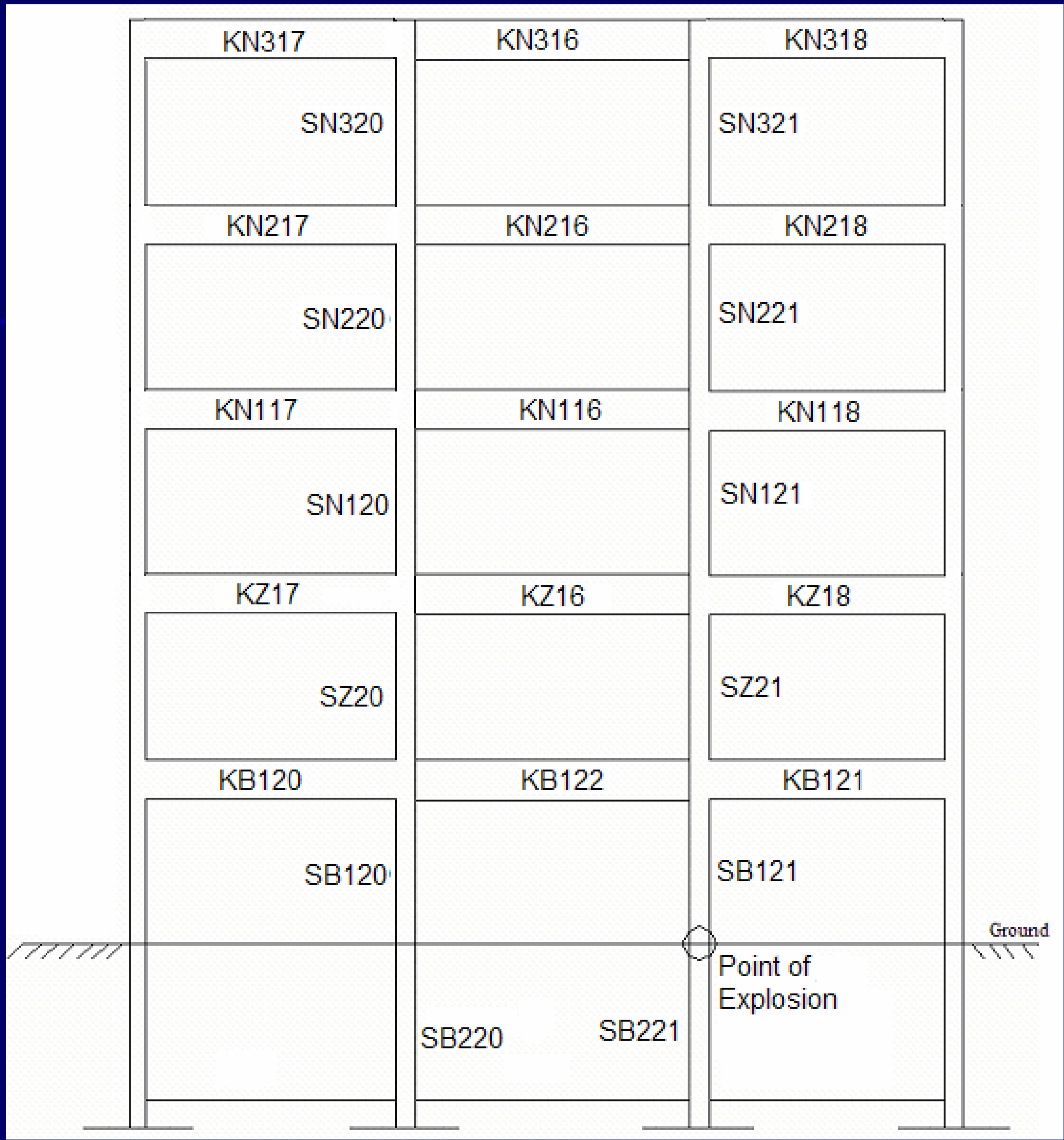
Location of explosion to the building

Blast Load Parameters

	Element	W (kg)	R (m)	Z $(m/kg^{1/3})$	Peak Overpressure (Mpa)	Peak Dynamic Pressure (Mpa)	Peak Reflected Pressure (Mpa)	Shock Front Velocity (m/sec)	Positive Phase Duration (sec)
1.BASEMENT	SB121	500	6,16	0,78	1,536	7,553	9,405	1279,36	0,008
	SB120	500	7,51	0,95	0,955	2,920	5,218	1030,87	0,009
GROUND	SZ21	500	7,28	0,92	1,035	3,428	5,775	1068,42	0,009
	SZ20	500	8,45	1,07	0,702	1,576	3,512	901,33	0,010
1.STOREY	SN121	500	9,13	1,15	0,578	1,069	2,724	830,66	0,011
	SN120	500	10,09	1,27	0,450	0,648	1,956	750,72	0,012
2.STOREY	SN221	500	11,34	1,43	0,338	0,366	1,337	673,05	0,013
	SN220	500	12,13	1,53	0,288	0,266	1,080	635,37	0,013
3.STOREY	SN321	500	13,75	1,73	0,215	0,148	0,734	575,93	0,015
	SN320	500	14,41	1,82	0,194	0,120	0,639	557,16	0,015
1.BASEMENT	SB121	750	6,16	0,68	2,25	16,26	14,83	1531,74	0,008
	SB120	750	7,51	0,83	1,29	5,31	7,58	1179,51	0,010
GROUND	SZ21	750	7,28	0,80	1,40	6,29	8,41	1226,31	0,010
	SZ20	750	8,45	0,93	1,00	3,18	5,51	1050,66	0,011
1.STOREY	SN121	750	9,13	1,00	0,82	2,14	4,27	962,30	0,011
	SN120	750	10,09	1,11	0,63	1,28	3,06	861,97	0,012
2.STOREY	SN221	750	11,34	1,25	0,47	0,71	2,07	763,95	0,013
	SN220	750	12,13	1,33	0,40	0,51	1,67	716,17	0,014
3.STOREY	SN321	750	13,75	1,51	0,29	0,28	1,11	640,43	0,015
	SN320	750	14,41	1,59	0,26	0,22	0,96	616,39	0,016

Blast Analysis of Structural Frame

- The frame members on which the plane is subjected to explosion directly are taken into consideration seperately.
- An element loaded by a blast can be modeled as a dynamic system with a single degree of freedom correspondig to its mid-span deflection.
- The response of the element is determined using ABAQUS, finite element program, which contains geometry and material non-linearity.



view of the x-z plane which is subjected directly to the explosion

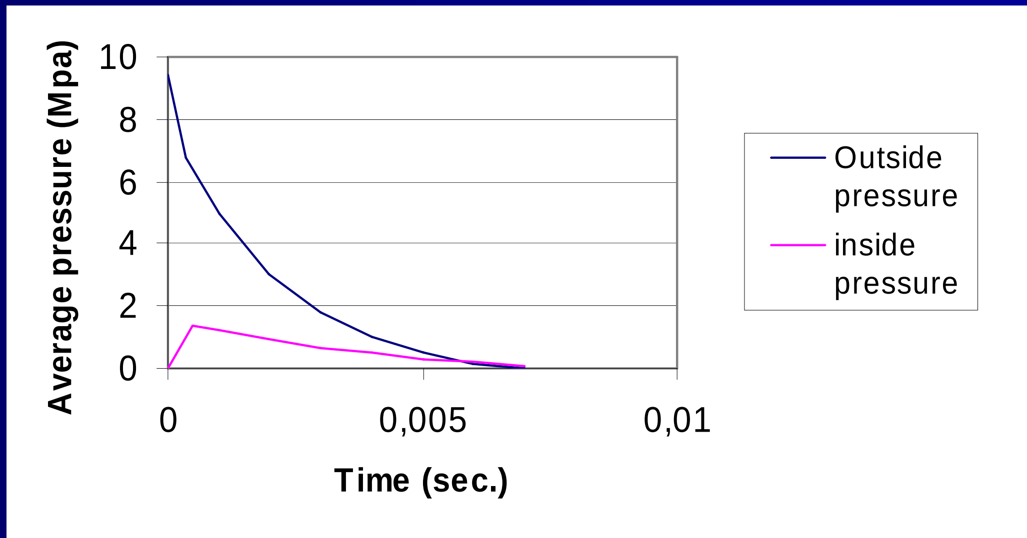
Modelling of the Element

- Structural frames are modeled using solid, homogenous element.
- Mesh design is a relatively fine mesh which provides moderate accuracy.
- The material is concrete (Young's modulus of 28500Mpa and Poisson's ratio of 0,2)
- The plasticity stress-strain curve is increased by the D.I.F
- The pressure-time load values are defined by applying to the surface of the element.

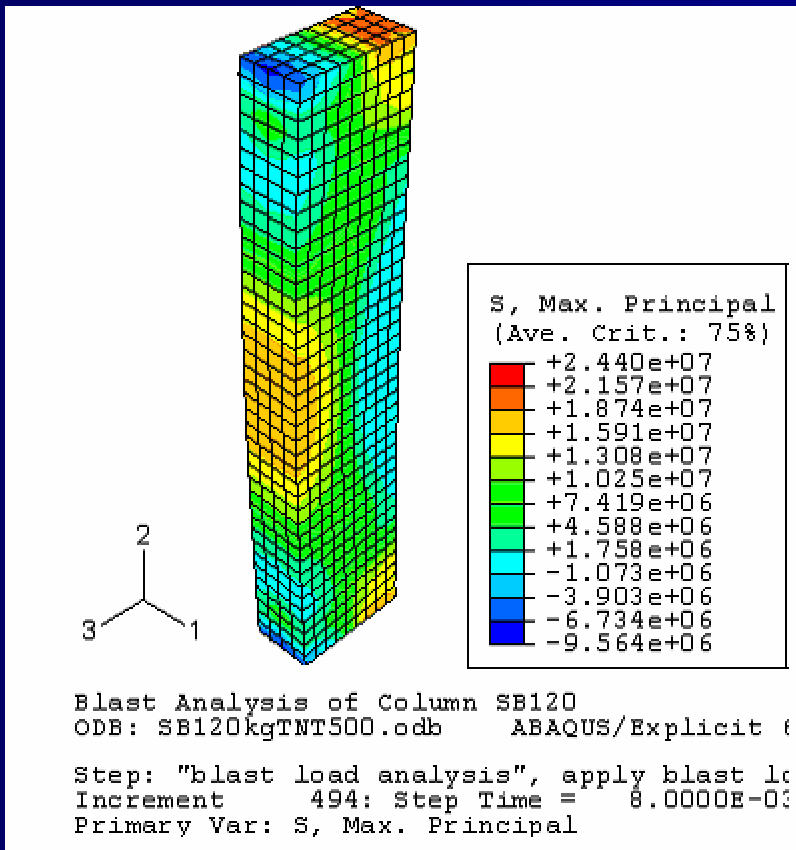
Blast Analysis of Column SB121 Subjected to 500kg of TNT Explosion

- W=500 kg of TNT , R=6,16m. and Z=0,78 (m/kg$^{1/3}$)
- P_{so}=1,54 Mpa
- P_r=9,405 Mpa
- t_o=0,008 sec.

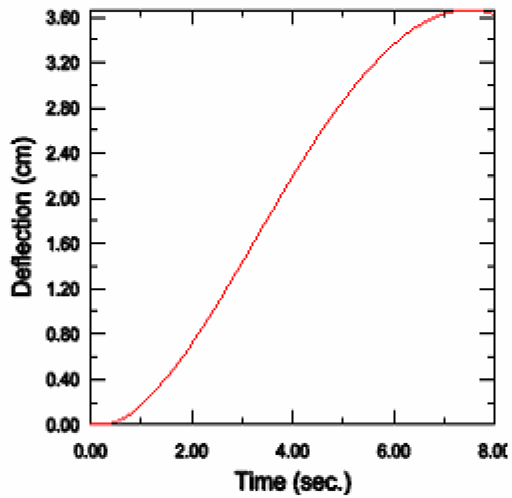
Blast loading of column SB121



Analysis Result



Max-stress distribution



Column mid-point deflection

Damage Assessment

- If the support rotation of the element is exceeded 4°, then it is said to be failed. By this way, three models are considered with the member removed according to the results are taken from the Abaqus program.
- The rest of the system is analyzed according to the vertical loads by using SAP2000 package program.
- Then the capacities of the rest of the structural frames are checked to be the limit or not.

The Analysis of the Damaged System

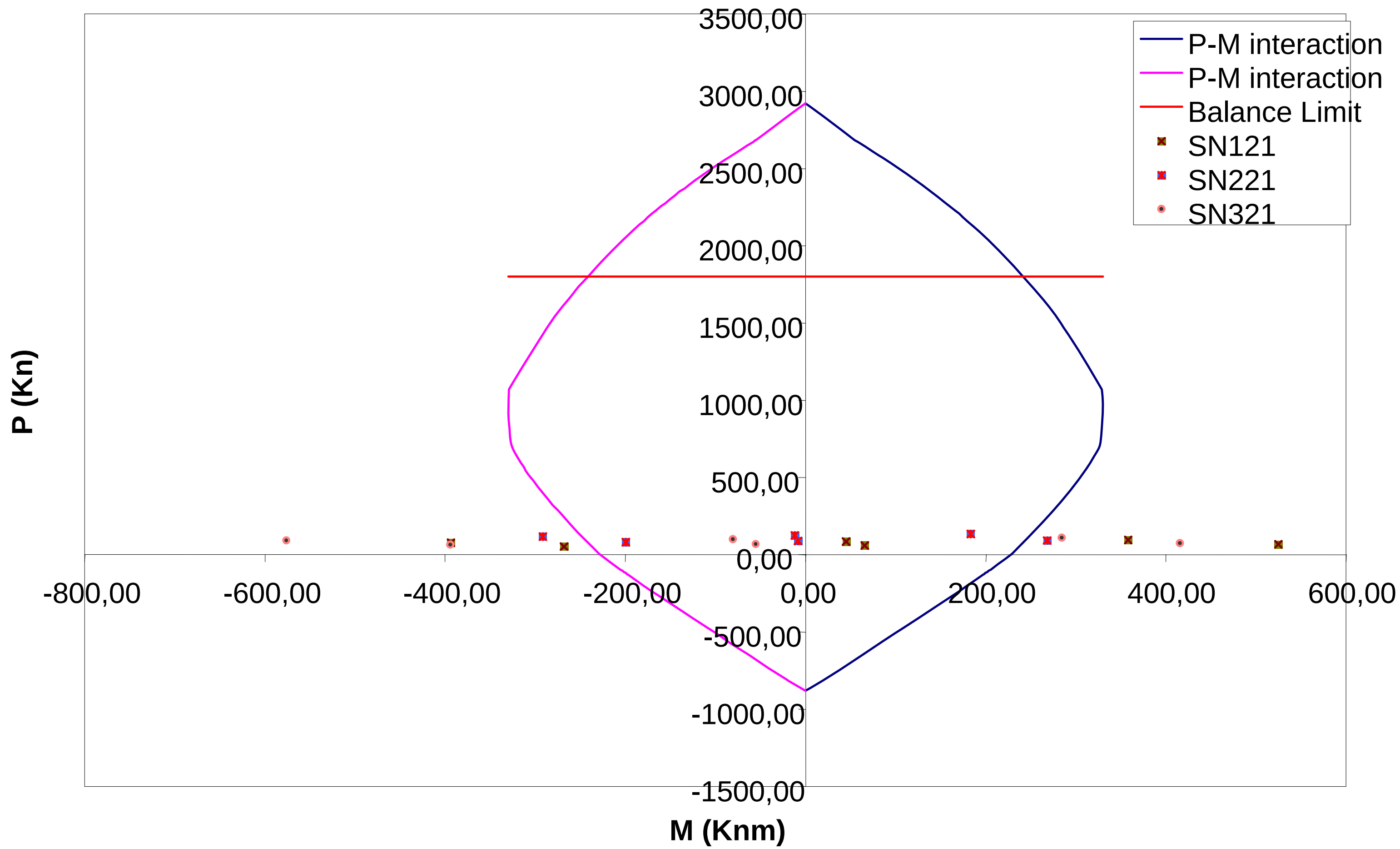
Three damage scenarios are prepared.

- Model 1 due to 750 kg of TNT
- Model 2 due to 1000 kg of TNT
- Model 3 due to 1500kg of TNT

Damage Scenarios

Damaged Scenario	Removed Columns	Removed Beams
Model 1	SB121	KB122, KB124, KZ18, KB142
Model 2	SB121, SZ21, SB120	KB122, KZ16, KB123, KB124, KZ18, KB137, KB142
Model 3	SB120, SZ20, SB121, SZ21	KB122, KZ16, KN116, KB123, KZ17, KB124, KZ18, KN118, KB137, KZ31, KB142, KZ36, KB149

Model 3 P-M interaction of column SN121, SN221, SN321 in y-direction



Summary of Results

Damaged Scenario	Removed Columns	Removed Beams	Damaged Columns	Damaged Beams
Model 1	SB121	KB122, KB124, KZ18, KB142	SB120, SZ20, SZ21, SN121	KB 119, KB 138, KB141
Model 2	SB121, SZ21, SB120	KB122, KZ16, KB123, KB124, KZ18, KB137, KB142	SZ20, SN120, SN220, SN121, SN221, SN321	KB 119, KB 138, KB141, KB143, KB121, KZ32, KZ35, KZ37, KZ15, KN116, KN118, KN135, KN137, KN143, KN216, KN218, KN235, KN237, KN238, KN316, KN317, KN318, KN335, KN337
Model 3	SB120, SZ20, SB121, SZ21	KB122, KZ16, KN116, KB123, KZ17, KB124, KZ18, KN118, KB137, KZ31, KB142, KZ36, KB149	SN120, SN220, SN320, SN121, SN221, SN321	KB 119, KB 138, KB141, KB143, KB121, KB120, KZ25, KZ32, KZ35, KZ37, KZ15, KZ43, KN115, KN125, KN132, KN135, KN137, KN143, KN217, KN218, KN225, KN235, KN237, KN238, KN325, KN335, KN337, KN343

Conclusion

- According to the results, the system affects significantly when the charge weight increases. But the actual charge weight of explosive used by the terrorist, the efficiency of the chemical reaction and the source location are not reliably predictable.
- The stand-off distance is the key parameter that determines the blast pressure so for protecting a structure is to keep the bomb as far away as possible by maximizing the stand-off distance.
- Blast has a characteristic of high amplitude. The results showed that if the member subjected to high pressure, they could cause big deformation on the element and cause to be exceed the support rotation so the elements which are close to explosion are damaged and failed.

THANK YOU FOR YOUR ATTENTION