Effect of Different Bracing Systems on the Multi-storey Building Subjected to Blast Loading

K.P. Thejaswi and Dr.D.K. Kulkarni

Abstract--- *The recent terrorist attacks and bomb attacks either in India or elsewhere in the world have shifted the attentions of structural designers towards the safety of the occupants and the structures. Especially the terrorist attack on the Twin Towers of America has resulted in an alarming situation and many researchers have focused their attention on the analysis and design of structures subjected to blast loadings. Many softwares available to structural engineers will also enable one to analyze the structure for the blast loading and design accordingly. In this project an attempt is made to analyze a G+6 storied symmetrical building which is subjected to blast loading. A comparative analysis is given when the structure is fitted with X Bracings, Diagonal Bracings, V bracings. For the analysis SAP2000, Version 18 is used along with RC Blast Software. Push over analysis is carried out for all the different cases. The results in the form of Storey Displacement and Storey Drift are compared for all the different cases considered.*

Keywords--- *Blast Load, Bracing System, RC Blast, SAP2000, Standoff Distance, Terrorist Attack.*

I. INTRODUCTION

SINCE 11th September 2001 the analysis and design for the blast loading have assumed importance when terrorist attacked the twin towers of America. Many terrorists have used the technique of vehicle bombing attacks against buildings. The use of vehicle bombs is a very common type of terrorist attack on structures. It is very important to protect some special buildings against the blast loadings.

These developments have led to the scheme of critically evaluating the structures against blast loading and designing them for the same. The investigation and design of structures when exposed to explosion loads require an understanding of the air explosion phenomenon and the dynamic response of structure. Analysis of structures exposed to blast loading is difficult because the uniform transient loads produced by the nearby detonation, combined with the localized structural response results in an extremely complex structural analysis problem.

The investigation of structures subjected to impact loading becomes difficult, because it has to take into account the localized nature of the structure, the large variation of pressure over a relatively small area and the fact of the blast pressure not arriving at every point on the structure at the same time.

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Usually the structures will experience the blast loading owed to armed actions, unplanned outbursts or terrorist actions. These type of blast loading may result in severe destruction or failure of the structure due to their very high intensity and dynamic nature. Failure of one important member in the locality of the source of the blast, may generate critical stress redistribution and lead to failure of other members, and ultimately the entire structure.

II. ABOUT BLAST LOADING

When the blast happens, an exothermic chemical reaction takes place in a period of milliseconds. The explosive material which is in the solid form or liquid form is transformed to dense, very hot, high pressure gas. The high pressure gas or compacted air travels outward on or after the source at supersonic velocities which is called the shock wave front. This compressed air enlarges at very enormous speeds and eventually influences steadiness by means of the adjacent air.

The warning for a bomb is well-defined by two fundamentals, the standoff distance R among the source of the blast and target, the bomb magnitude (charge weight W). The incident peak overpressure P_{so} are improved by a reflection fact or as the shock wave meets an objective or structure in its track. Reflection aspects depend on intensity of the shock wave.

The blast features define a transient pulse of pressure which is discharged from the source of the blast The transient pulse consists of positive phase during which, incident pressure in the environment considerably go beyond the ambient pressure, often followed by a negative phase during which the incident pressure falls underneath the ambient pressure. It is the relation between the transient pulse and an affected structure which governs the dynamic response of a specific structure.

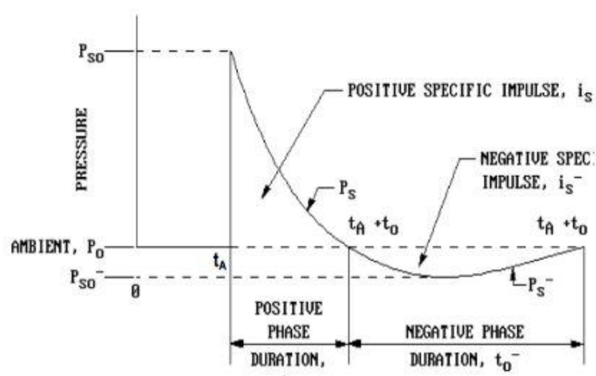

Figure 1: Typical Blast Pressure with Time

There exists two phases in pressure time profile:

a. Portion beyond the ambient is called positive phase of duration.
b. Portion under ambient is called negative phase of duration.

The negative phase has an extended duration and a lesser intensity compared to the positive duration. It can be noted that, the duration of the positive phase blast wave upsurges causing in a lesser amplitude and extensive duration shock pulse as the standoff distance increases.

The explosives when they are located close to the structure enforce a great impulse, high intensity pressure load over a confined region of a structure. The explosives when they are located far from the structure create a lesser intensity and longer duration uniform pressure distribution over the complete structure. Thus the whole structure is bounded by the shockwave with reflection and diversion effects.

In the course of negative phase the damaged structure might be subjected to impact by debris that can cause extra damage. If the external walls of the structure are capable of withstanding the blast load, the shock front enters over the window and door openings resulting in floors, walls, ceilings, materials in addition to the people to unexpected pressures and fragments from shattered windows, doors etc. The building materials which are not accomplished of sustaining the blast wave will crack, further split and moved by the dynamic pressure that directly tracks the shock front. The building contents and the individuals will be expelled and dropped in the path of blast wave propagation. Like this way the blast will spread all through the building.

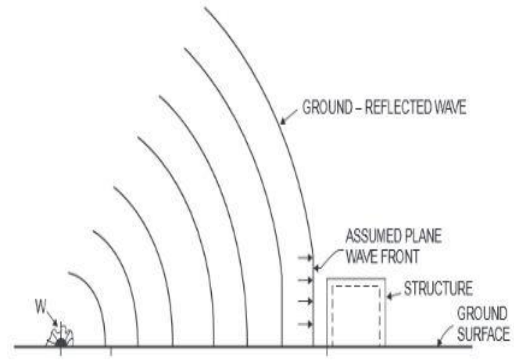

Figure 2: Propagating Blast Wave

A. Blast Wave Scaling Laws

All impact factors are essentially reliant on the measure of vitality discharged by an explosion as an impact wave and the separation from the blast. The standardized explanation of the blast effects is given by scaling distance relative to $(E/Po)^{1/3}$ and scaling pressure relative to Po, where E is the energy release (kJ) and Po the ambient pressure (typically 100 kN/m2). In general the basic explosive input or charge weight W is expressed as an equivalent mass of TNT. Outcomes are then given as a function of the dimensional distance parameter. Scaling laws provide parametric connections between a specific explosion and a standard charge of the same substance.

$$\text{Scaled distance}(Z) = \frac{R}{W^{1/3}}$$

Where, R is the actual effective distance on or after the blast W is expressed in pounds or kilograms.

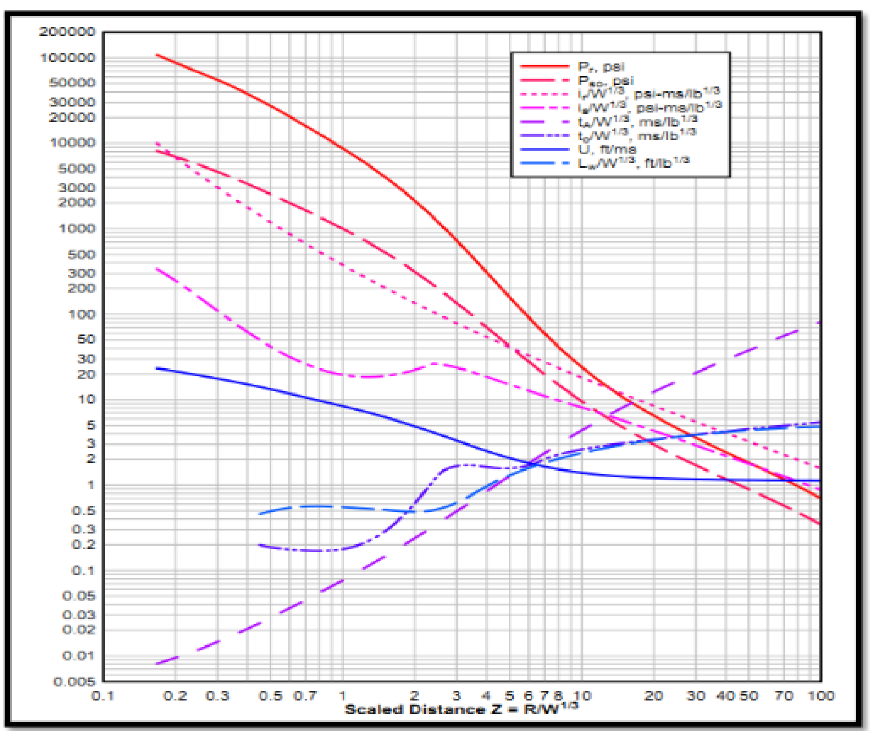

Figure 3: Positive Phase Shock Wave Parameters for a Hemispherical TNT Explosion on the Surface at Sea Level

In this project an attempt is made to analyze a G+6 storied symmetrical building which is subjected to blast loading. A comparative analysis is given when the structure is fitted with X bracings, diagonal bracings and V bracings. For the analysis SAP2000, Version 18 is used along with RC Blast software. For different cases Push over analysis is carried out.

The results in the form of displacements and storey drift are compared for all the different cases considered.

Plan dimension: 12x18m

Total height of the building: 21.2m

Type of concrete used: M30

Type of rebar: HYSD500

Column dimension: 600X600mm

Beam dimension: 300X600mm

Thickness of the slab: 200mm

Thickness of wall: 230mm

Typical storey height: 3.2m

Bottom storey height: 2m

Spacing of beams in X-direction: 6m

Bays in X-direction: 2 bays

Spacing of beams in Y-direction: 6m

Bays in Y-direction: 3 bays

Live load considered on slab: 4 kN/m^2 (IS 875-Part II)

Super dead load considered on slab: 1 kN/m^2

Wall load: 14.72 kN/m

Loads patterns considered:

a. Dead load
b. Live load
c. Super dead load
d. Wall load
e. Blast load

Type of steel used for bracing: Fe250

III. Blast Pressure Parameters

A sample blast pressure calculation are shown below

Case 1:

W= 100 kg

Stand-off distance at ground level, R = 20 m

Scaled distance $Z = R/W^{1/3} = 4.31\ m/kg^{1/3}$

$Z = 4.31\ m/kg^{1/3}$

Positive pressure P_r= 137.3 kPa

Positive impulse= 686.9 kPa-ms

Positive duration tA= 16.5 ms

Negative pressure= 18.1 kPa

Negative impulse= 620.2 kPa-ms

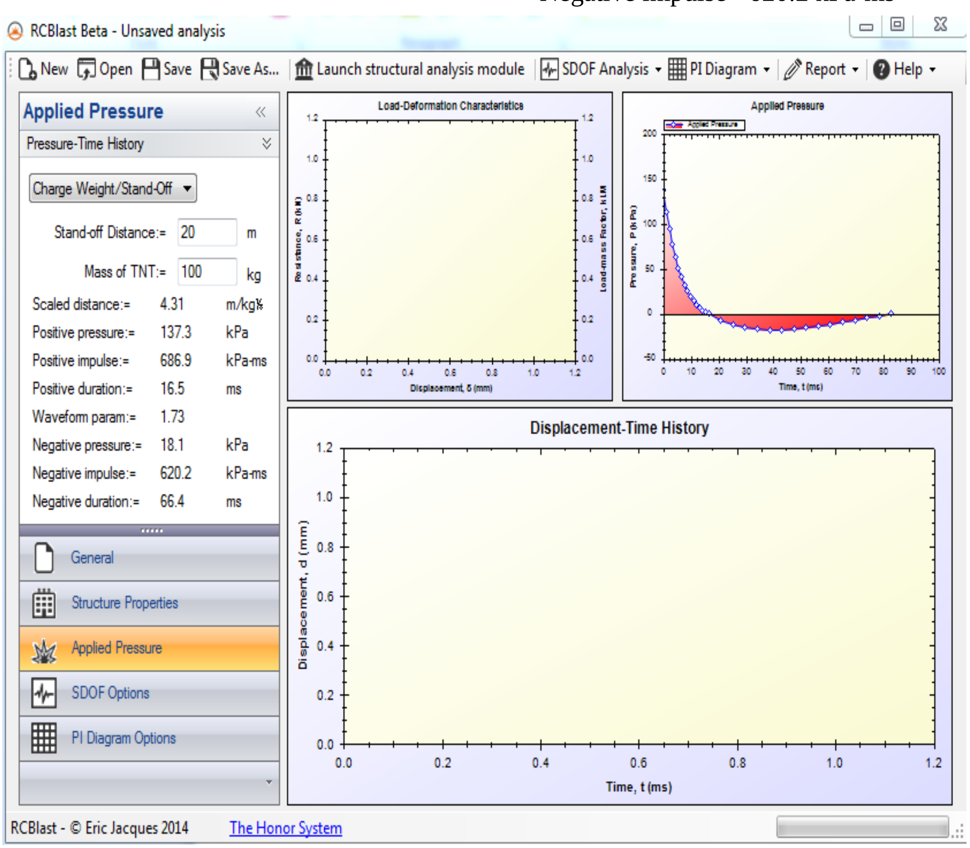

Figure 4: Windows Screen of RC Blast Software to Calculate Blast Pressure and Time

As the height of building rises, scaled distance increases correspondingly and the value of blast pressure reduces by some amount.

These blasts reflected positive pressures are applied to the front side of building in the form of blast force. These blast forces can be obtained by multiplying the pressures with the contributing area of each node. A sample calculation for forces acting on the nodes due to blast weight of 100kg at standoff distance of 20m is shown below,

1. For node no 83;
   Positive pressure= 137.3 kPa
   Blast force P_{83} = 0.1373x0.25x1000= 34.32kN
2. For node no 86;
   Positive pressure = 80.8 kPa
   Blast force P_{86} = 0.0808x0.5x1000 =40.4kN
3. For node no 89;
   Positive pressure = 56.1 kPa
   Blast force P_{89} = 0.0561x0.5x1000 = 28.50kN
4. For node no 80;
   Positive pressure = 42.5 kPa
   Blast force P_{80} = 0.0425x0.25x1000 = 10.63 kN

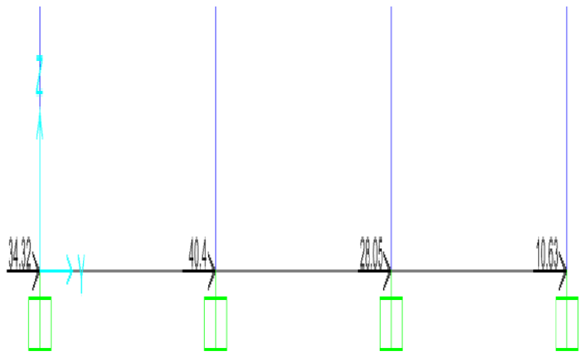

Figure 5: Application of Blast Load Laterally to the Nodes

Applied blast loads on the front side of the structure

At height 2m

1. For node 13;
   Positive pressure = 136.0 kPa
   Blast force P_{13} = 0.136x0.5x1000 = 68 Kn
2. For node 14;
   Positive pressure = 80.4 kPa
   Blast force P_{14} = 0.0804x1x1000 = 80.4kN
3. For node 15;
   Positive pressure = 55.9 kPa
4. For node 6;
   Positive pressure = 42.4 kPa
   Blast force P_6 = 0.0424x0.5x1000 = 21.2 kN
   Blast force P_{15} = 0.0559x1x1000 = 59 kN

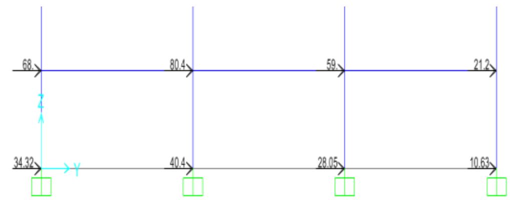

Figure 6: Application of Blast Load Laterally to the Nodes at 2m Height

Similarly for all nodes the blast load is calculated

Table 1: Application of Blast Loads at Front Side Nodes

Number of floors, from top	Normal building (mm)	X- type braced building (mm)	Diagonal bracing, (mm)	Diagonal bracing, (mm)	V- type bracing, (mm)
1st	44.6	7.0	11.4	10.5	7.7
2nd	42.6	6.7	10.9	10.2	7.4
3rd	38.8	6.2	10.1	9.5	6.8
4th	32.7	5.5	8.8	8.3	6.0
5th	24.1	4.5	7.0	6.6	4.9
6th	13.5	3.2	4.7	4.5	3.5
7th	2.9	1.4	1.8	1.4	1.5

Table 2: Displacement of Structure at Different Node

Node number	*Stand off distance, z (m)*	*Positive pressure (kN/m^2)*	*Time (ms)*	*Applied blast load (kN)*
83	20.00	1373	16.5	34.32
86	26.00	808	18.3	40.40
89	32.00	561	19.7	28.05
80	38.00	425	20.8	10.63
13	20.09	1360	16.5	68.00
14	26.07	804	18.3	80.40
15	32.06	559	19.7	59.00
6	38.05	424	20.8	21.20
29	20.66	1280	16.7	64.00
24	26.51	780	18.4	70.80
23	32.41	549	19.8	54.90
18	38.35	419	20.9	20.95
37	21.69	1156	17.1	57.80
38	27.32	738	18.6	73.80
39	33.08	531	19.9	53.10
30	38.91	410	21.0	20.50
49	23.12	1015	17.5	50.75
50	28.47	685	18.9	68.50
51	34.03	507	20.1	50.70
42	39.73	397	21.1	19.85
54	24.88	879	18.0	43.95
55	29.91	629	19.2	62.90
56	35.25	479	20.3	47.90
57	40.78	382	21.3	19.10
66	26.90	759	18.5	37.95
67	31.62	572	19.6	57.20
68	36.71	449	20.6	44090
69	42.04	365	21.5	18.25
1	29.14	658	19.1	16.45
2	33.54	519	20.0	25.95
3	38.38	419	20.9	20.95
4	43.51	347	21.7	10.93

Similarly for the middle and end nodes the blast force is applied

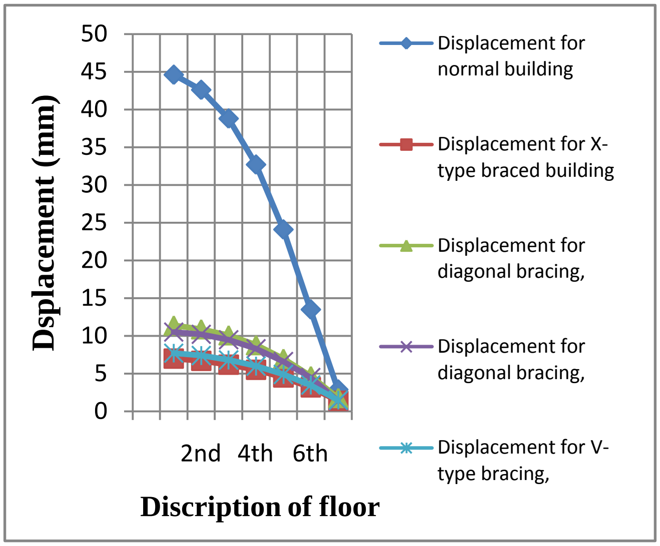

Figure 6: Graph of No of Stories v/s Displacements

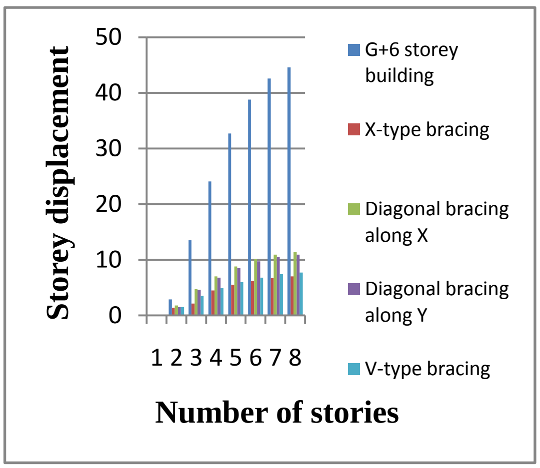

Figure 7: Graph Showing No. of Stories V/S Storey Displacement

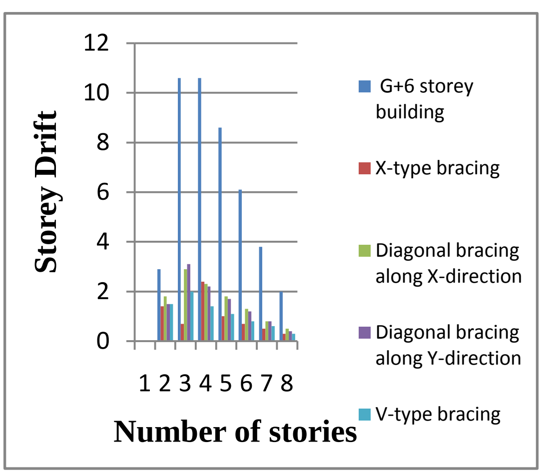

Figure 8: Graph Showing No. of Stories V/S Storey Drift

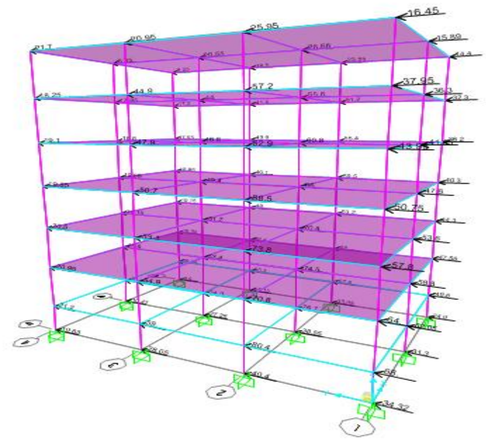

Figure 9: 3-D View of the Building with the Application of Blast Loadings at the Nodes

IV. Conclusion

1) As the standoff distance increases the positive pressure. From the above values it can be noted that stand off distance is inversely proportional to pressure.
2) Contribution factor of 0.25 is considered for outer nodes but for inner nodes it is taken as 0.5 at the ground level and at the top floor, whereas the contribution factor of 0.5 is considered for outer nodes and for inner nodes it is taken as 1 for all other floors. Therefore at the outer nodes the application of blast load is lesser compared to that of the inner nodes.
3) As the positive pressure decreases the time taken for the blast load to reach the structure also decreases.
4) The displacement for the G+6 storey normal building was found to be more as compared to that of the other type of braced structure.
5) Among all the braced type of structures the X-type bracing is found to be efficient when the blast load was applied laterally
6) Subsequently X-type bracing the V-type bracing showed less displacement compared to other two type of diagonal bracing.
7) The storey displacement is found to be more at the top floor, where as the storey drift is found to more at the middle floors as compared to top floors.

References

[1]. API WSD 2000, “Recommended Practice for Planning”, Designing and Construction Fixed offshore Platforms-Working Stress Design, December, 2002.
[2]. D.O. Dusenberry, “Handbook for Blast-Resistant Design of Buildings”, 2010.
[3]. G.C. Mays and P.D. Smith, “Blast Effects on Buildngs”, G.C.Mays, P.D.Smith, Thomas Telford, Londan, 2003
[4]. M.N. Chimeh and P. Homami, “Efficiency of Bracing Systems for Seismic Rehabilitation of Stell Structures”, Proceedings of the Fifthteenth World Conference on Earthquake Engineering *Lisbon*, Portugal, 2012.
[5]. IS: 4991-1968, Criteria for Blast Resistant Design of Structures for Explosions above Ground, Reaffirmed, 2003.
[6]. A. Jon, Schmidt, “Blast Design-Equivalent Static Methods”, Structural Engineers Association of Kanas and Missouri, Kanas City, 2007.

[7]. R. Logaraja, "Blast Resistant Structure", International Journal of advanced technology in engineering and science, Vol. 2, Pp. 261-264, 2014.
[8]. S.N. Madhekar and Z.A.L. Qureshi, "Response of 45 Storey High Rise RCC Building Under Blast Load", Advances in Structural Engineering, Springer India, Matsagar (ed.), Pp. 435-448, 2015.
[9]. P. Mendis, A. Gupta, T. Ngo and J. Rmasay, "Blast Loading and Blast Effects on Structures–An Overview", EJSCE International journal Loading on Structures, Pp. 76-91, 2007.
[10]. S. Singla, P. Singla and A. Singla, "Computation Of Blast Loading For A Multi Storeyed Framed Building, Vol. 4, Pp. 759-766.
[11]. PIP STC01018, BLAST Resistant Building Criteria, Process Industry Practices (PIP), Construction Industry Institute, The University of Texas at Austin, Texas, 2006.
[12]. TM 5-1300, Structures to Resist the Effects of Accidental Explosions, Technical Manual TM 5-1300, Department of the Army, Navy, and Air Force, Washington, DC, 1990.