Investigations on the influence of matrix and textile on the response of textile reinforced concrete slabs under impact loading

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Abstract. Textile Reinforced Concrete (TRC) is gaining its popularity as a construction material. It is essential to investigate new materials to quantify its expected structural performance and integrity. The purposed study is to investigate the influence of material type and volume fraction of textile and type of matrix on the impact behaviour of textile reinforced concrete slabs. Both glass and basalt textiles were used in the investigations. Based on the investigations, it is concluded that the type of binder influences the impact resistance at first crack as well as the delamination possibility. Glass textile reinforced concrete slabs show more displacement and more residual capacity compared to basalt textile reinforced concrete slabs. With increased number of layers, the basalt textile reinforced concrete slabs exhibited decrease in impact resistance due to delamination. As energy level increases, glass textile reinforced slabs show increase in peak displacement whereas basalt textile reinforced concrete slabs show a decrease. The investigations reported will be useful for extending the knowledge of textile reinforced concrete for various impact resistant applications.

Keywords. Textile reinforced concrete; impact; slabs; glass textile; basalt textile.

1. Introduction

Textile reinforced concrete (TRC) can be customized to suit specific application by appropriately selecting binder and textile combinations. TRC is composed of a fine grained cementitious binding matrix and non-metallic textile as reinforcement. Various types of fibers namely glass, carbon, polypropylene or aramid are used to manufacture textiles [1–8]. Both strength and toughness of TRC is related to the mechanical anchoring provided by the fabric structure and the matrix-reinforcement bond [9, 10]. As an impact resistant material, TRC performs better than many conventional materials and it can also be used to protect existing concrete components [11–13]. This is due to the capability to dissipate the imparted energy through several interacting damage modes and fiber breakage. Experimental studies were conducted to study the low-velocity impact behaviour of textile reinforced concrete, and it was noticed that it is possible to avoid complete fracture if fabrics are used instead of fibers [13]. The behaviour of alkali resistant (AR)-glass fabric reinforced concrete produced using pultrusion process showed that, under low velocity flexural impact, as the number of fabric layer increases the impact resistance increases with minimal deflection. Hence, when existing concrete panels are protected by TRC, scabbing of concrete from the back face of the structural component can

considerably be reduced. Padaki *et al* [11] studied about the failure of textile composites under low velocity impact and observed that the textile composites dissipate the imparted energy through several interacting damage modes than simple deformation and the fiber breakage occurs prior to major damage. The impact resistance shown by glass fabric reinforced thin sandwich panels were better compared to that of carbon fabric reinforced thin sandwich panels [14]. TRC reinforced with open textile structure showed improved impact resistance compared to TRC reinforced with denser textile structure [15]. Most of the impact tests using fibers and textile depict various failure modes such as brittle, brittle followed by ductile, ductile followed by brittle and purely ductile. These are mainly due to the influence of type of fiber material and its various characteristics, which influence the response. The object's ability to resist high-rate loading is its impact resistance. In this context, it is seen that the impact resistance is one of the most important properties for a structural designer to consider and it is difficult to quantify. In many applications, it is a critical measure of service life that can affect the product safety and liability. Hence, it is very essential to examine the impact behaviour while using any new type of evolving material for various applications.

From practical application point of view, it is noticed that when TRC is used as precast elements for residential, industrial, or commercial constructions, wherein the resistance to impact damage may be one of the important

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parameter in the selection process. Considering this scenario, the investigations highlighting the performance of TRC with various textiles under low energy impact loading is limited. The present paper reports the performance and findings from an experimental investigation carried out to find the effect of textile and matrix characteristics on the impact behaviour of glass and basalt textile reinforced concrete slabs. The data from the investigations provide a knowledge addition pertaining to impact behaviour of TRC with various characteristics of textiles, which is currently limited in literature.

2. Experimental investigations

The impact behaviour of textile reinforced concrete slabs was determined to assess the influence of mix composition, type of material used as textile, influence of number of layers of textile and effect of weight of textile in TRC.

2.1 Materials used

The binder used in TRC consists of cement, fly ash, silica fume, water, super plasticizer, quartz powder and quartz sand with water to binder ratio of 0.4. The details of mix are given in table 1. Two types of mixes 'a' and 'b' were used in this investigation. The main difference between the two mixes 'a' and 'b' is the quantity of fine aggregate (i.e., quartz sand and quartz powder). In mix-b, quartz sand is reduced by 67.4% and quartz powder is reduced by 38.8% than that in mix-a, which can bring down the cost of mix. Three types of textiles T1, T2 and T3 are used in the investigations. The specifications provided by the manufacturer for various textiles are provided in table 2.

2.2 Test specimen fabrication

For the entire investigations, TRC slabs of size $450 \times 450 \times 50$ mm were cast for testing under impact loads. The details of the slabs are given in table 3. The

Table 1. Mix proportion (weight ratio) of binder.

Materials used/characteristic parameters	Mix-a	Mix-b
Cement	1.0	1.0
Fly ash	0.357	0.333
Silica fume	0.071	0.058
Quartz sand	1.020	0.333
Quartz powder	0.612	0.375
Water	0.571	0.416
Water/binder ratio	0.4	0.3
Cube compressive strength (MPa) – mean and coefficient of variation	44.5 ($\pm 4.2\%$)	47.42 ($\pm 8.4\%$)

Table 2. Details of textiles used.

Type of textile	Textile material	Mesh opening (mm $\times$ mm)	Weight per unit area (g/m ²)	Tensile strength (kN/m)
T1	Glass	25 $\times$ 25	225	45
T2	Glass	25 $\times$ 25	420	100
T3	Basalt	25 $\times$ 25	350	70

Table 3. Details of TRC slabs.

Specimen ID	Mix used	No. of layers	Impact energy level used for test (J)
T1-5a	a	5	50 150 200
T1-15a	a	15	50 100 150 200
T3-5a	a	5	50 100 150
T3-15a	a	15	50 100 150
T1-5b	b	5	50 100 150
T1-10b	b	10	50 100 150
T2-5b	b	5	50 100 150
T2-10b	b	10	50 100 150

numbers in the specimen id represents the number of textile layers. The required number of layers of textiles was cut according to the size of slab. The ingredients of the binder were dry mixed for about four minutes. Then the super plasticizer (Glenium 3000 NS) was added such that 75% of it is well mixed with 75% of the total water and mixed for about three minutes. Further, remaining water and super plasticizer were mixed together and added. Then the subsequent mixing was carried out for about three minutes. Casting was done by placing the binder in the mould, and then the required number of textile layers were placed inside the mould over the mix according to the positioning type and again covered with mix to the overall thickness of 50 mm.

Figure 1. Position of textile layers in TRC.

Different position of glass textile layers as shown in figure 1 were attempted to study the impact resistance. The specimen with textile placed in the middle position is labeled as ML, textiles placed on the extreme side leaving cover of 10 mm is labeled as FE, textile layers placed on one side and folded to other side to form required number of textiles FL, textiles placed on both sides as FB, textiles placed layer by layer throughout the thickness as LL. Binder was poured into the mould and at the final layer, the surface was leveled to attain a uniform finish. TRC slabs were cured up to 28 days and subsequently all the specimens were kept at a cool dry place till testing.

2.3 Test set-up

The instrumented impact testing machine CEAST INSTRON- 9350 shown in figure 2 is used for testing of specimens. It consists of a rectangular self-supporting type frame which was welded to steel short columns and bolted to the rigid floor. To prevent the slab from lifting during impact and to simulate simply supported condition, the slab was clamped down with the steel frame using C- clamps as shown in figure 2. A hemispherical insert of diameter 40

mm fitted to tup and carriage frame having a total mass of 9.155 kg was used for applying impact on the specimen. During the impact, the impacting tup (striker) sends signal to the Data Acquisition System (DAS) where it is recorded as impact force value at each time step. Various response parameters such as energy absorbed by the target and peak force are recorded from the machine and the damage is observed after each impact. During the test, the impact force was directly measured from the load cell that is instrumented inside the tup. A minimum of three numbers of specimens were tested in each case and different impact energy levels (50 J to 200 J) were used in the testing as given in table 3. To finalize the first energy level to be applied, initial trials were made on various specimens and it was found that in all cases there was no damage (absence of crack) till an energy level of 50 J. Beyond 150 J, the specimen's impact resistance was found to decrease. Hence 150 J was considered as the upper limit for the impact energy in the present investigations. Starting from 50 J, the energy level was increased sequentially till 150 J in each specimen.

3. Results and discussion

Test results pertaining to the measured response characteristics and observed damages are presented in the following sections. TRC slabs are tested under instrumented drop weight impact by varying impact energy levels to investigate the influence of mix composition, volume fraction, and type of textile material. It is needed to subtract the generalized inertial load ($P_i(t)$) from the measured hammer load ($P_t(t)$) to arrive at the actual impact load ($P_l(t)$) on the specimen as given in Eq. (3). The inertial load, $P_i(t)$, is calculated by using the principle of virtual work [16]. Banthia *et al* [17] conducted many tests to study the acceleration distribution along the length of the specimen. It is observed that the accelerations are indeed simple mathematical functions; the distribution being linear for plain and sinusoidal for conventionally reinforced concrete. Thus appropriate equations from (1) and (2) can be chosen to calculate the generalized inertial load $P_i(t)$.

Figure 2. Test set-up used for TRC slabs.

$$P_i(t) = \rho A \ddot{u}_0(t) \left[\frac{l}{3} + \frac{8h^3}{3l^2} \right] \quad (\text{for linear acceleration distribution}) \quad (1)$$

and

$$P_i(t) = \rho A \ddot{u}_0(t) \left[\frac{l}{2} + \frac{2\pi^2 h^3}{3l^2} \right] \quad (\text{for sinusoidal acceleration distribution}) \quad (2)$$

where ρ is the mass density of concrete, A is the cross sectional area of the specimen, $\ddot{u}_0(t)$ is the specimen acceleration at the center, h is the overhang and l is the test span.

$$P_l(t) = P_t(t) - P_i(t) \quad (3)$$

Thus the actual impact load is calculated for all the specimens and the force time histories were plotted.

3.1 Effect of layer position

Different positioning of textile was tried out with 10 layers of T1 textile with mix 'a'. It has been investigated to ensure the position of textile for further testing. The typical impact force history and energy absorption history for T1 glass TRC specimens with textiles placed at different position tested under impact energy of 100 J are shown in figures 3 and 4, respectively. From the figures it is clearly depicted that the TRC slab specimens with textiles positioned at the middle show maximum impact resistance and maximum energy absorption. By placing textile layers at the middle, the bending deformation is negligible and membrane action is governing its behaviour. This has resulted in remarkably high energy level for the ML specimens. The specimens with textiles on both front and back sides showed the least value as half of the textile layers did not contribute to the impact resistance. Other three strategies showed similar

Figure 3. Impact force history for different position of textile.

Figure 4. Energy history for different position of textile.

response. In case of energy absorption, the specimens with textiles at one extreme side showed the least value. Placing the textiles layer by layer and on both sides showed similar response except that the FB specimens absorb energy for more time. The specimens with folded type of textile showed the second least energy absorption. Hence further investigations were carried out on TRC slabs with textiles positioned at the middle.

From the investigations, it is concluded that when textiles are placed near to the surface of cracking, there is more chance of textile rupture as well as for the brittle type of composite failure. In addition, the cover of concrete from the surface of cracking also has a major influence with respect to impact response and energy absorption ability [18]. As the thickness of cover increases, the chance for brittle nature of failure is reduced. The energy absorption is also more in such cases. Due to effectiveness of more number of layers when they are placed altogether reduces the tendency for rupture of the textiles, especially when they are placed in the middle of TRC slab. The ML type of textile positioning in TRC has more cover thickness compared to other type of specimens. Due to these reasons, ML type of specimens is having better performance compared to other specimens.

3.2 Effect of textile type and number of layers

3.2a Using binder mix 'a': T1 glass and T3 basalt textile reinforced concrete slabs which uses mix 'a' binder were compared. In order to arrive on the energy absorbing capacity of TRC slabs, each slab was provided with repetitive impact with increasing level of impact energy. In this way, it is easy to estimate the maximum energy absorbing capacity. Hence, first impact had energy of 50 J. The force time history is shown in figure 5 for T1 slabs under impact load. It can be observed from figure that for first impact of 50 J energy the compression and restitution phase are same. It means that the slab specimen behaves elastically and the impact duration is short, 0.9 ms, and the

Figure 5. Force time history plot for T1 specimens (mix a). (a) T1-5a. (b) T1-15a.

peak impact force developed is recorded as 15 kN. On the other side, when next impact is made with 150 J energy multi peaks are observed which indicates fracture of matrix as well as fibre in textile layer. A peak force represents maximum energy absorption due to textile stretching at the critical section and the impact duration is recorded as about 0.5 ms, and restitution phase shows some residual energy which attenuates later. It is interesting to note that for impact with energy 200 J the peak impact force reduce to approximately 29 kN. This indicates strength degradation due to damage in both fibres and matrix. However, the specimens do not fragment and further load is resisted due to presence of fibre. Hence it can be concluded that the specimen with 5 layers GTRC can absorb impact energy of 150 J without disintegration.

The impact force versus time histories for various glass and basalt TRC slabs at different impact energy levels are shown in figures 5–8. From figure 5, it is observed that the impact force increases as imparted energy increases from 50 J to 100 J. For 5 layer reinforced T1 glass TRC slabs, it is observed that the impact response is comparatively more ductile for impact at energy level of 50 J. On further increase in energy, (i.e., impact at 150 J), behaviour shows narrow curve indicating the loss of ductility. At the next energy level (at 200 J), the peak load gets reduced but the residual capacity is prolonged over a time period from 0.3 ms to 1 ms. In T1 glass TRC slabs, the increase in number of layers does not show any difference in impact response at energy level of 50 J (see figures 5 and 6). The impact at an energy level of 100 J shows maximum impact resistance and there is no sudden decrease in load. The peak load gets reduced gradually for 150 J and 200 J but the residual capacity gets increased. Hence it can be concluded that as number of layers increases from 5 to 15, there is considerable difference in the post peak behaviour of TRC slabs, indicating that the energy absorption increases as number of layers increases.

Compared to T1 TRC slabs, T3 TRC slabs are having more impact resistance at 50 J; its ductility is relatively less (see figures 5 and 6). The impact resistance decreases at 150 J and residual capacity is prolonged from 0.3 ms to 0.8 ms. On comparison of figure 7(a) and 7(b), it is seen that in T3 TRC, the increase in number of layers decreases the impact resistance, which implies delamination of textile has taken place. In addition, there was no difference in the impact resistance for different energy levels for 15 layer reinforced T3 TRC.

From figures 5 to 7, it can be concluded that the residual capacity of TRC slabs gets increased with increase in number of layers of textiles in both T1 and T3 textiles. Further, the maximum impact resistance and ductility is relatively more for T1 TRC slabs when compared to T3 TRC slabs. Similarly from figure 5(b), maximum force is developed due to the impact of 100 J, and for higher level of impact energy there is reduction in peak impact load. It can only happen when the impacts are higher. In figure 6, force time history for T3 TRC slab is plotted. Similar explanation is valid for this case also.

On close examination at formation of first crack (see figure 7), it can be observed that peak impact force increases slightly. During the occurrence of first crack, the impact resistance of TRC slabs with Mix-a, reinforced with 5 and 15 layers of T1 glass textiles was found to be almost same (figure 7a). However, the impact force was more for 15 layer basalt reinforced specimen when compared to 5 layer reinforced specimen (figure 7b). This may be attributed to the increased stiffness of basalt textiles compared to glass textiles.

3.2b Using binder mix 'b': The performance of TRC slabs with glass textiles T1 and T2 along with Mix-b were compared. The impact force versus time for these specimens is given in figures 8–10. When using mix-b, the slabs with T1 textiles (see figure 8) show relatively more ductile impact response at 50 J compared to T2

Figure 6. Force time history plot for T3 specimens (mix a). (a) T3-5a. (b) T3-15a.

Figure 7. Impact responses of TRC slabs with Mix 'a' at first crack. (a) T1 textile reinforced slabs. (b) T3 textile reinforced slabs.

Figure 8. Force time history plot for T1 specimens (mix b). (a) T1-5b. (b) T1-10b.

Figure 9. Force time history plot for T2 specimens (mix b). (a) T2-5b. (b) T2-10b.

textile reinforced slabs (see figure 9). From figure 8(a), it is observed that, the impact force is almost same for 100 J and 150 J.

In addition, the overall trend of the impact force history is also same for these energy levels. However, at lower energy level of 50 J, the impact force vs. time curve is broader. When using T1 textiles there is an increase in maximum impact resistance for 10 layer glass TRC slab as compared to 5 layer glass TRC slab (see figure 8). However, the slabs that are reinforced with T2 textiles do not show any significant increase in maximum impact resistance. The trend of residual impact resistance is also same for T1 and T2 textile reinforced slabs at respective energy levels. When number of layer increases, the impact force history does not show any difference at 50 J for both T1 and T2 reinforced slabs. The impact force at 100 J is more than that at 150 J for 10 layer T1 reinforced slabs. This indicates that delamination due to bonding defects would have happened between textile layers and matrix.

When TRC slabs are reinforced with T2 textiles (figure 9), the impact force is more at 100 J than at 150 J, which again indicates that as the amount of fiber at particular location increases, it leads to lesser bonding characteristics when Mix-b is used. In all cases, the maximum impact resistance is observed at an energy level of 100 J. Further, from figures 8 and 9, it can be observed that different mix design exhibit monotonic increase in peak load. The specimen with more layers indicates higher impact force value.

When Mix-b is used, there is an increase in the impact force for 10 layer T1 textile reinforced slabs compared to 5 layer reinforced specimen. However, the impact resistance at first crack is less for 10 layer T2 reinforced specimen compared to 5 layer T2 reinforced specimen, which indicates that delamination chances are more as weight per unit area of textile increases. It is also observed that when using Mix-b, there are more chances of lesser bond between textile and matrix (figure 10(a) and 10(b)).

Figure 10. Impact responses of various TRC slabs at first crack (50 J). (a) 5 layer T1 & T2 TRC slabs with Mix-b. (b) 10 layer T1 & T2 TRC slabs with Mix-b.

3.3 Effect of mix composition

The TRC slabs reinforced with 5 layers of T1 glass textile with mix 'a' and mix 'b' were compared. The typical force time history at maximum energy is shown in figure 11. From the figure it is clearly seen that the peak force is maximum for slabs with mix 'a' which may be due to the presence of more amount of quartz sand and quartz powder to increase the friction between matrix and textile thereby increasing the bond between them.

3.4 Displacement of TRC slabs

Centre point displacement in TRC slab specimen is measured using a LVDT. It is observed that for higher impact energy peak displacements are also high, as expected. Midpoint displacement–time histories of various glass and basalt reinforced textile reinforced concrete slabs are presented in figures 12 and 13, respectively. When energy level is 50 J, the displacement is minimum and the residual

displacement is almost zero (see figure 12). However, for maximum energy level, the residual displacement also increases. As number of layers of textile increases, the displacement also increases for respective energy levels. It is also noticed that the time corresponding to which the peak displacement occurs also varies for different energy levels.

Figure 14 depicts the trend of displacement for various imparted energies on TRC slabs, and it is noticed that for both glass and basalt textile reinforced slabs, the displacement is almost same till an energy level of 100 J and beyond that the rate of increase of displacement with respect to energy changes from its linear trend. In addition, the maximum displacing ability of both types of slabs was not showing any influence on the number of layers. Figure 14 compares the energy absorption TRC slabs with T1 and T3 textile reinforcement. It is clearly indicated that T1 TRC slab specimens exhibit better energy absorption for some midpoint displacement.

3.5 Damage pattern

The observed damage patterns of various specimens that were impacted at maximum energy level reported in table 3 are shown in figures 15–18. In all cases of T1 textile reinforced specimens, only the top impression was formed on the impacting face as shown in figure 15(a). However at the bottom face, scabbing was observed as seen in figure 15(b) and 15(c). The cracks formed in both types of specimens were hairline in nature. The number of cracks was more for 15 layer reinforced specimen compared to 5 layer specimen. The amount of scabbing depends on the number of layers of textile, thickness of specimen and impact energy, etc.

While comparing 5 and 15 layers of T1 textile reinforced slabs containing mix-a, it is noticed that the severity of the localized damage is more in 15 layered specimen. Since, all

Figure 11. Effect of mix on impact force at 150 J.

Figure 12. Displacement histories of T1 textile reinforced slabs. (a) T1-5a. (b) T1-15a.

Figure 13. Displacement histories of T3 textile reinforced slabs. (a) T3-5a. (b) T3-15a.

Figure 14. Midpoint displacement vs. energy imparted on TRC slabs.

layers are placed altogether; the increased severity of localized scabbing can be mainly due to the possible delamination of glass textile from matrix, when more number of layers is used. In case of basalt textile reinforced

specimens, the severity of scabbing and the spread of damaged area were more compared to glass textile reinforced specimen. Among 5 and 15 layered basalt textile reinforced slabs, 15 layer specimens showed more damage (see figure 16(a) and 16(b)).

From figures 15 and 16 it can be observed that area of scabbing is less in case of TRC slabs with T1 textiles than in TRC slabs with T3 textiles. Hence, TRC slabs with T1 textile performs better under repeated impact cases. While comparing the performance of mixes 'a' and 'b', it is noticed that the bonding of textile with matrix are more intense while using Mix-a. The damage of specimens with Mix-b showed more scabbing for 5 layer T1 textile reinforced specimen compared to 10 layer reinforced specimen (figure 17(a) and 17(b)).

While using 5 layers of T2 textile, the slabs were broken, indicating that 420 g/m^2 weight has more chances of less bonding with Mix-b (figure 18(a) and 18(b)). Also, the crack width was more when compared to specimens which used Mix-a. However, the slabs were not disintegrated into fragments, when 10 layers of T2 were used; still all cracks propagated in a global manner and hence exhibit very good

Figure 15. Typical damage pattern of T1 glass TRC slabs with mix a. (a) T1-5a: Front face (Top). (b) T1-5a: Back face. (c) T1-15a Back face.

Figure 16. Typical damage pattern of T3 basalt TRC slabs with mix a. (a) T3-5a. (b) T3-15a.

Figure 17. Typical damage pattern of T1 glass TRC slabs with mix b. (a) T1-5b. (b) T1-10b.

Figure 18. Typical damage pattern of T2 glass TRC slabs with mix b. (a) T2-5b. (b) T2-10b.

structural integrity. This property is desirable in case of repeated impact loading. Lesser fibre volume indicates radial crack throughout the thickness which shows poor performance under impact condition. Overall, the damage pattern in TRC slab indicates that to take advantage of TRC the matrix must crack, then only load is transferred to textile.

4. Conclusions

Primary focus of the paper was to investigate the effect of textile and matrix characteristics on the impact response of glass and basalt textile reinforced concrete slabs. Based on the studies, the following conclusions were drawn.

- The positioning of number of layers of textile has major influence on the impact resistance in TRC. The impact resistance and energy absorption was found to be maximum when layers of glass textiles were placed altogether at the middle of the specimen. In such cases, the behaviour of TRC panel is governed by membrane action rather than bending.
- The number of textile layers influences the impact force and there is found to be an optimal number of layers, beyond which the increase in impact resistance is not significant. In both glass and basalt textile reinforced TRC, 5 layers have shown optimum performance with respect to various energy levels. The post peak impact response was better for basalt when compared to glass reinforced TRC and providing more number of layers improves the residual capacity in both cases.
- Increasing the number of layers increases the maximum displacement in glass textile reinforced TRC, whereas the maximum displacement is same for both glass and basalt if 5 number of layers are used.
- The proportion of fine aggregate used in binder of TRC has major influence on the impact resistance of TRC and more proportion of aggregate leads to better bonding characteristics compared to binder with lesser fine aggregate.
- TRC specimens with basalt textile show significant delamination at various energy level compared to glass textile reinforced TRC.
- Even after application of impact energy multiple time on the same specimen, the TRC slabs did not exhibit any fragmentation and their structural integrity remained intact with minor scabbing.

Based on the investigations presented in this paper, it is concluded that TRC panels exhibited excellent performance against low velocity impacts. The use of TRC can be extended for its use as crash barriers, noise barriers, tunnel lining, rock fall protection, missile shielding, low energy debris impact, etc. However, based on the application, the energy level needs to be ensured and separate tests needs to be conducted for its final applicability.

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List of symbols

$P_i(t)$ actual impact load

$P_t(t)$	measured hammer load
$P_i(t)$	inertial load
ρ	mass density of concrete
A	cross sectional area of the specimen
$\ddot{u}_0(t)$	specimen acceleration at the center
h	overhang
l	test span

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