CSCE Annual Conference
Growing with youth – Croître avec les jeunes

Laval (Greater Montréal)
June 12 - 15, 2019

IMPACT LOAD EFFECTS ON POST-INSTALLED SCREW ANCHORS

Aliu, Abdul-Hamid[1,3], Abass, Braimah[1,4], and Fred Tai[2,5]
[1] Carleton University, Canada
[2] Simpson Strong Tie Inc.
[3] aliuabdulhamid@cmail.carleton.ca
[4] abassbraimah@cmail.carleton.ca
[5] ftai@strongtie.com

Abstract: This paper presents the results of a study designed to investigate the effect of impulse loads of short durations on Titen HD®, one of the mechanical screw anchors manufactured by Simpson® Inc. Three anchor diameters (6.4, 9.5 and 12.7 mm) at manufacturer specified embedment depths were tested under static and impulse type loading in shear and tension. Static test results showed that anchorage failure was by a mixture of pullout and concrete cone and that the failure loads were fairly predicted by the concrete capacity design (CCD) method for anchor under both tension and shear loading. The impact test results on the other hand showed that the anchorage systems achieved higher capacities under the high strain rate loading conditions. Dynamic increase factors (DIF) of 1.1, 1.5, and 1.1 are recommended for the 6.4-mm, 9.5-mm, and 12.7-mm diameter anchors, respectively tested under tension impulse type loading. The DIF for the anchors under impulse type shear loading were 0.8, 1.1, and 1.2 for the 6.4-mm, 9.5-mm, and 12.7-mm diameter anchors, respectively.

1 Introduction

Terrorist attacks around the world have shown that most injuries, apart from casualties or fatalities resulting from the direct collapse of structural components, are caused by flying glass shards (Mallonee et al. 1996; Norville and Conrath 2001). In this regard, fenestrations in buildings, particularly government and high-profile buildings such as embassies are often retrofitted with anti-shatter film to mitigate injuries and fatalities due to the glass shard hazards. Often the retrofits involve attaching the anti-shatter films to the frames which are in turn attached to the structure of the façade with steel anchors. To maintain the integrity of these fenestrations, adequate connection should be ensured between window frames and structure of the façade. It is important that framing and its anchorages be designed to resist the dynamic blast loads on the window glass lite, assuming the entire load will be transmitted to the anchorage systems without fracture of the glass (Norville and Conrath 2001). Conventional window anchors often lack the strength to resist the imposed dynamic blast loads and thus can result in dislodgement of retrofitted windows and their projections into the interior of buildings with potential to cause injury and fatality of the occupants.

Due to their flexibility and wide range of application, post-installed anchors remain a viable option for anchoring retrofitted and blast-resistant window frames to reinforced concrete and masonry façade structural members. The ability of screw anchors to be unscrewed when not desired or during replacement make them quite unique in the class of post-installed anchors. However, the behaviour of post-installed screw anchors under high-strain rates associated with impact and blast loads is less researched and need to be comprehensively investigated. Most research on anchor behavior is concerned with strain-rates associated with static or quasi-static conditions. Fuchs et al. (Fuchs, Eligehausen, and Breen 1995) proposed the Concrete Capacity Design (CCD) approach for anchors failing by concrete cone which has now been adopted for design in many national design codes; for example, CSA A23.3-14 (CSA (Canadian Standards Association) 2014) and ACI-318 (ACI Committee 318 2008) design codes for Canada and the USA respectively.

2 Objectives

The Objective of the paper is to present an experimental investigation to assess the behavior of three different diameters of the screw anchors, manufactured by Simpson Strong Tie Inc., under both static and impulse-type impact loading. Also, to propose dynamic increase factors (DIF) for use in design of anchors under high strain rates of loading. More specifically, the study was aimed at:

- assessing the ultimate tensile and shear capacities of each anchor diameter, installed at the manufacturer's recommended embedment depths, under static and impulsive loading.
- comparing the failure modes associated with static and dynamic loading conditions.
- proposing appropriate DIF for use in design of anchorages under impulse-type loading conditions.

3 Background

Under high loading rates, the capacities of both steel and concrete have been observed to increase. This phenomenon has been confirmed by Malvar and Crawford(Malvar and Crawford 1998a, 1998b) who conducted extensive literature review on the subject to characterize the strength of concrete and steel at high rates of loading. The authors observed a significant increase of up to 50% in the strength of reinforcing steel and by more than 200% for the strength of concrete in both compression and tension. Bischoff and Perry (Bischoff and Perry 1991) investigated the effect of loading rate on the compressive strength of concrete and reported up to 30%. While Fu et al. (Fu, Erki, and Seckin 1991) observed an increase of between 18 to 65% in tensile strength of concrete under high loading rates. The effect of the increase in concrete and steel strength on the behaviour of post-installed anchors at high rates has not been established.

Generally, post-installed anchors are divided into two broad categories: bonded and mechanical anchors. Bonded anchors transfer load through bond between steel anchor and the bonding agent and between the bonding agent and the walls of the substrate material. The main mechanism of load transfer is adhesion and micro-keying. Mechanical anchors on the other hand, mainly transfer load through friction, keying, bearing or a combination of these. Screw anchors mainly transfer loads through mechanical interlock by cutting a thread into the walls of the pre-drilled hole. These types of anchors are suitable for use in both cracked and uncracked concrete.

The CCD method identifies the following failure modes for post-installed anchors:

- For anchors under tensile loading
  - Concrete cone/breakout failure;
  - Anchor pullout failure;
  - Bond failure (bonded anchors);
  - Splitting failure; and
  - Steel fracture failure;
- For anchors under shear loading
  - Concrete edge breakout failure;
  - Concrete pryout failure; and
  - Steel fracture failure.

The concrete breakout capacity of anchors based on the CCD approach is given in Equation 1. The equation is based on the nominal concrete tensile stress acting over the projected area of the failure breakout pyramid at 35º side inclination. The equation was proposed by Fuchs et al. (Fuchs, Eligehausen, and Breen 1995), employing k- factors to calibrate contribution of the nominal strength of concrete, the projected area of the breakout pyramid and size effect of the anchorage system. The size effect contribution was based on Bazant's size effect law (Bažant, Kim, and Pfeiffer 1986) to account for the reduction of nominal concrete stress at failure as embedment depth increases.

[1] $\boldsymbol{N_u = k_n \cdot \sqrt{f'_c} \cdot h_{ef}^{1.5}}$

Where $\mathbf{f'_c}$ is the compressive strength of concrete and $\boldsymbol{h_{ef}}$ is the effective embedment depth.

$k_n = k_1 \cdot k_2 \cdot k_3$ = 14.7 for post installed anchors

k_1 is a calibration factor applied to tensile strength of concrete ($\mathbf{k_1 \cdot \sqrt{f'_c}}$)

k_2 is a calibration factor applied to the projected area of the failure pyramid ($\mathbf{k_2 h_{ef}^2}$)

k_3 is a calibration factor expressing the size effect contribution ($\mathbf{k_3 h_{ef}^{-0.5}}$)

Kuenzlen et al. (Kuenzlen, Jurgen; Sippel 2001) and Olsen et al. (Olsen, Pregartner, and Lamanna 2012) observed that Equation 1 did not yield accurate results for screw anchors. Kuenzlen (Kuenzlen 2004) proposed a modification to the calculation of the effective depth, while Olsen et al. (Olsen, Pregartner, and Lamanna 2012) recommended limits for the nominal anchor embedment as well as anchor spacing. The modified embedment depth is given in Equation 2, and pictorially explained by Figure 1.

[2] $\boldsymbol{h_{ef} = 0.85 \cdot (h_{nom} - 0.5 \cdot h_t - h_s)}$

Where $\boldsymbol{h_{nom}}$ is the nominal minimum embedment depth, $\boldsymbol{h_t}$ is the pitch of the thread and $\boldsymbol{h_s}$ is the distance between the tip of the anchor and the start of the threads.

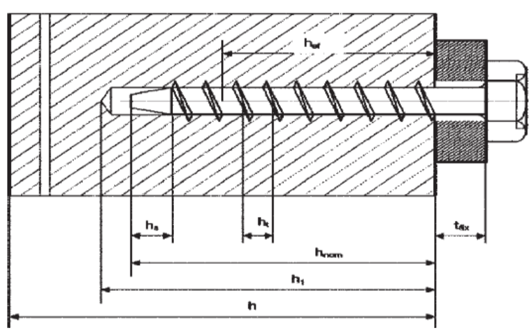


Figure 1: Parameter for calculation of effective depth(ICC Evaluation Services 2009)

The Canadian Standards Association (CSA) Design of Reinforced Concrete Structures code (CSA A23.3-14 2014) does not permit the calculation of the pullout capacity of post-installed anchors and only prescribes a value based on the 5% fractile of test results obtained in accordance with ACI 355.2 code (ACI Committee 355 2007). Splitting failure of the concrete substrate occurs when the depth of the concrete is inadequate. To prevent splitting failure, a minimum concrete depth requirement is specified by the code.

The steel fracture failure capacity is based on the fracture of the effective tensile and shear area of the steel anchor loaded in tension or in shear. The nominal tensile or shear capacity of an anchor failing in steel fracture is given by Equation 3.

[3] $\boldsymbol{N_u, V_u = A_{se} f_{ut}}$

Where $\boldsymbol{A_{se}}$ is the effective cross-sectional area of the anchor and $\boldsymbol{f_{ut}}$ is the ultimate tensile strength of steel.

The concrete breakout capacity under shear loading based on the CCD approach is given by Equation 4.

The equation is based on effective bearing length of the anchor in shear, $\boldsymbol{l}$, the diameter of the anchor, $\boldsymbol{d_o}$,and the edge distance, $\boldsymbol{c_1}$,all in SI units. The effective bearing length of screw anchors is equal to the modified effective embedment depth.

[4] $\boldsymbol{V_u = 1.08 . \left(\frac{l}{d_o}\right)^{0.2} . \sqrt{d_o f'_c} . c_1^{1.5}}$

Generally, there is limited information on anchors subjected to high strain rate loading. In fact, most of the research on high strain rate behaviour of anchors has concentrated on bonded and undercut anchors, no research was found in the literature on screw anchors. Braimah et al. (Braimah, Contestabile, and Guilbeault 2009) and Ahmed and Braimah (Ahmed and Braimah 2017) investigated the behavior of adhesive steel anchors under impulse-type loading and behavior of undercut anchors subjected to high strain rate loading. For the adhesive anchors under impulse type-type loading, different substrate materials, as well as angles of installation were investigated. DIF values of 1.2 and 2.5 were recommended for 90º and 45º installation angles for limestone substrate and 1.2 and 3.2 respectively for concrete substrate materials. For the undercut anchors, a maximum DIF in tension of 1.6 was recommended at strain rate of 10^3 s^{-1}. Solomos and Berra (Solomos and Berra 2006) employed the Split-Hopkinson Pressure Bar Technique (SHPB) (Ross 1989) to investigate the behavior of anchors in concrete under dynamic tensile loading and found DIF in the order of 1.07 to 1.67. Rodriguez et al. (Rodriguez et al. 2001) investigated the behavior of anchors in uncracked concrete under dynamic tensile loading and observed for wedge type anchors (expansion anchors) either pullout or pull-through failure modes under dynamic loading conditions. The authors recommended further research to evaluate the behaviour of the anchors under seismic loading. Rodriguez et al. also found that grouted anchors pulled out of cracked concrete under dynamic conditions.

4 Experimental investigation

The test series presented in this paper is part of a larger experimental program designed to evaluate the behaviour of post-installed anchors manufactured by Simpson Strong Tie® Inc. under impact loading. The experimental investigation of Titen HD® screw anchor, is presented herein. Three anchor diameters , 6.4, 9.5 and 12.7 mm, installed at the manufacturer recommended effective embedment depths in concrete beams were tested. The experimental setup was designed to meet the requirements of ASTM E488/488M-15 (ASTM 2015).

The anchors were first tested under static loading to obtain their tensile and shear behaviour and then under drop-mass to obtain their dynamic tensile and shear behaviour. Table 1 presents the test matrix for the anchors.

Table 1: Experimental test matrix

Diameter (mm)	Embedment Depth (mm)	Number of Samples (Tension)		Number of Samples (Shear)	
		Static Test	Dynamic Test	Static Test	Dynamic Test
6.4	49.3	3	9	3	3
9.5	61.0	3	3	3	3
12.7	75.9	3	6	3	3

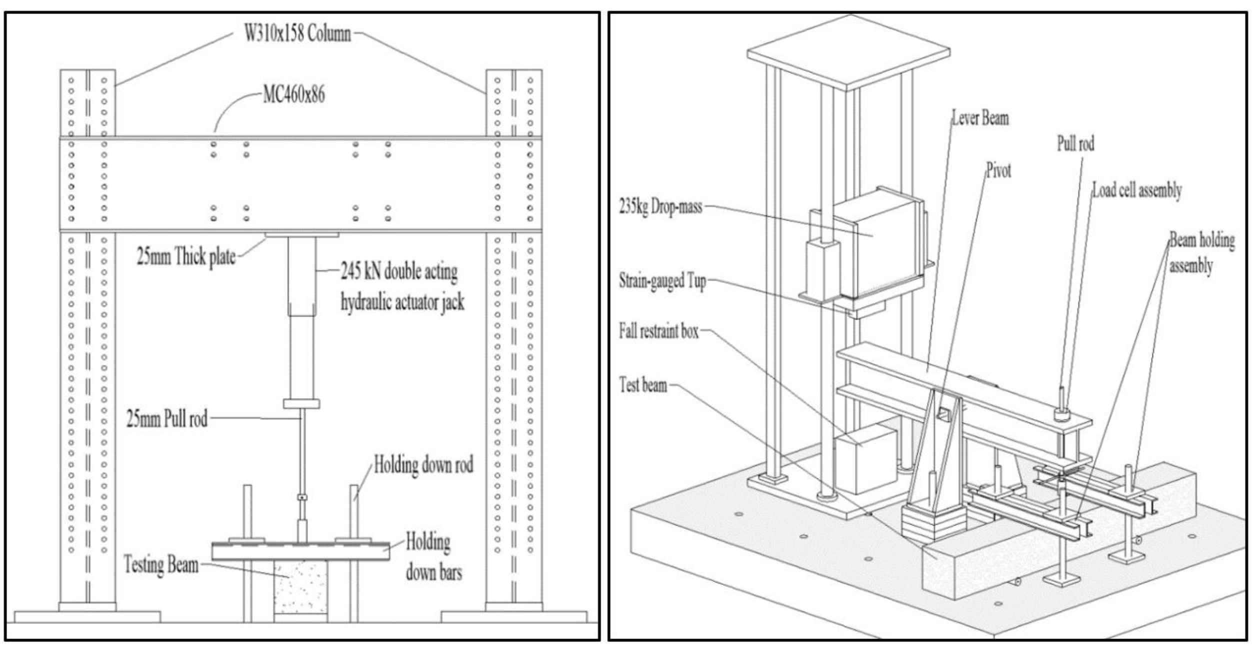
Test Set up

The static test setup is shown in Figure 2a and comprises a 245-kN (55-kip) double-acting MTS actuator mounted on a portal steel reaction frame. The actuator was mounted on a steel plate pad at mid-span of the cross-beam and controlled by an MTS 458.10 control system. Steel anchor displacements were measured with two calibrated string potentiometers (String-Pots) connected to an outrigger attached to the pull rod (Figure 2a).

The impact tests were conducted using a drop-mass test frame (Figure 2b). The drop-mass test frame consists of a 235-kg mass installed on two circular steel guide bars. The 235-kg mass was raised to a predetermined test height with a hydraulic lifting system and released to free-fall onto one end of a first-class lever system. The drop-mass was equipped with a strain-gauged tup to measure the impact force. A photo-interruptor installed on the drop-mass frame was used to trigger the data acquisition system.

The first-class lever system consists of a 2.10-m W250×167 steel beam pivoted with two welded steel frames. The pivot of the lever system was positioned to yield a mechanical advantage of 1.0.

To measure the tensile or shear load on the anchor, a PicoCoulomB (PCB) piezoelectric load cell was placed on top of the steel beam and tightened against the nut of the pull rod. A 12.7-mm thick durometer was placed between the lever and the load cell to lengthen the duration of the load that was transferred to the anchor.



(a) (b)

Figure 2: Experimental test frames: a) Static Test; b) Impact Test

Sample preparation

Anchor installation was done following the manufacturer prescribed installation sequence (Strong-tie, n.d.) as follows:

- Drill hole to required hole depth with hammer drill using a nominal drill bit diameter equal to the nominal diameter of screw anchor;
- Clean hole by brushing the sides with a stiff brush and blowing out the dust with compressed air;
- Install anchor in the hole by screwing using a torque wrench until prescribed torque.

The anchors were connected to the pull-rod of the test frames through a 50-mm diameter coupler shown on Figure 3 for the tension test. For the shear test, shear loading plates meeting the requirements of ASTM E488/488M-15 (ASTM 2015) were used. Two sheets of polytetrafluorethylene (PTFE), one on loading plate and the other on concrete face, were employed in the shear test to minimize friction between the loading plates and the concrete face.

Testing

The test procedure adopted involved installing the screw anchor in the concrete beam, restraining the concrete beam to the laboratory strong floor by using back-to-back steel channel beams and 25-mm diameter threaded dywidag rods, and applying the loading on the installed anchors.

For the static testing, the anchor was loaded through the vertical movement of the actuator. The actuator was set to move in a displacement-controlled rate of 0.04, 0.05 and 0.07 mm/s for the 6.4-, 9.5- and 12.7-mm diameter anchors respectively. The loading rate was chosen to ensure the anchors failed within 1 to 3 minutes.

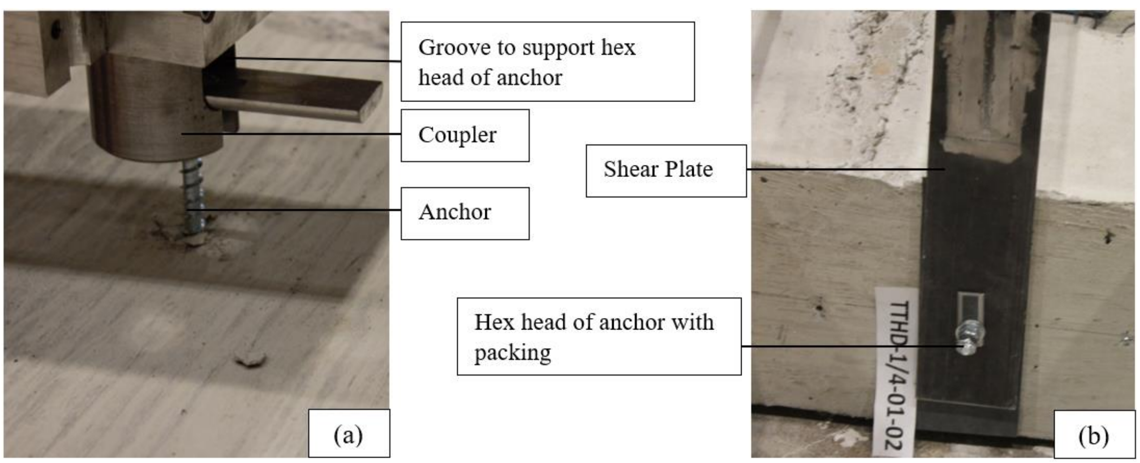


Figure 3: Coupler for tension test (a), Shear plate for shear test (b)

For the impact test, the drop-mass was raised to a predetermined height and then released to freefall onto the lever. For the first test in each series, the drop-mass was increased gradually until the anchor failed. This was done to establish a drop height that resulted in energy close to the failure load of the anchor. Subsequent tests were carried out close to the established drop height resulting in failure of the anchor. Displacement measurement for both static and impact tests were accomplished with linear vertical transducers (LVDT) and String-Pots. A strain gauge was installed on at least one anchor from each group to obtain stress-strain behavior as well as strain rates from the tests.

5 Experimental results and discussion

Static test results

The experimental failure loads and failure modes under static loading are presented in this section and then compared with the predicted failure loads and failure modes based on the CCD method.

Tension tests

All the anchors tested in tension failed in a mixed mode of anchor pullout and concrete breakout. A shallow concrete cone was formed close to the surface of the concrete beam while a longer length of the anchor pulled out of the concrete (Figure 4a). The predicted failure mode for the 6.4-mm diameter anchor was steel fracture, while the predicted failure mode for the 9.5-mm and 12.7-mm diameter anchors was concrete breakout failure.

In general, the tension failure loads increased with increase in anchor diameter in both experimental tests and the CCD method. The experimental failure loads were higher than the predicted CCD failure load for the 9.5-mm and 12.7-mm diameter anchorage where the failure mode was pullout with a shallow concrete breakout cone. For the 6.4-mm diameter where the predicted failure mode by the CCD method was steel fracture and the experimental failure mode was by the mixed mode, the experimental failure load was lower than the predicted failure load. However, the experimental and predicted failure loads were within 76% of each other. The 6.4-mm diameter anchor failed at 76% of the predicted load, while the 9.5-mm and 12.7-mm diameter anchors failed at loads 4% and 10% higher than the predicted failure loads. Table 2 shows the tension failure loads. The average failure cone angles for the anchors were 27^{o}, 25^{o} and 18^{o} for the 6.4-mm, 9.5-mm and 12.7-mm diameter anchors respectively. These failure cone angles are less than the 35^{o} proposed by the CCD approach.

Shear tests

All the anchors tested in shear failed in a steel fracture failure mode (Figure 4b). This was expected as the edge distances were chosen to preclude concrete breakout failure. In general, the failure loads increased with increase in anchor diameter with the experimental failure consistently higher than the predicted shear failure loads (Table 2). For the 6.4-mm and 12.7-mm diameter anchors, the experimental failure loads were about 6% and 12% more than predicted failure loads while for the 9.5-mm diameter anchors, the experimental failure load was 2% lower than the predicted failure loads.

Table 2: Tensile loading results for static testing

Diameter (mm)	Tension				Average cone angle (deg)	Shear	
	Predicted (CCD)		Experimental			Predicted	Experimental
	Load (kN)	Failure Mode	Load (kN)	Failure Mode		Load (kN)	Load (kN)
6.4	28.3	Steel	21.4	Mixed	27	17.1	18.1
9.5	40.6	Cone	42.4	Mixed	25	38.0	37.4
12.7	56.5	Cone	62.4	Mixed	18	65.8	73.4

(a) (b)

Figure 4: Failure modes for anchors: a) Tension; b) Shear

Impact test result

In drop-mass testing, as the chosen drop height may result in an input energy that is more than or less than the load required to fail the anchorage system, it unlikely to obtain the exact failure load. Anchorage systems testing in the drop-mass test frame are best evaluated by a “Go-No-Go” testing procedure such as the Bruceton Method (ASTM 2010). However, the Bruceton Method requires many samples, making the testing time consuming and expensive.

In this test, the objective was to investigate the highest impulse that the anchors could absorb without failure. The two main parameters considered were the peak impact load and the associated impulse. The peak load was taken as the maximum amplitude of the load-time curve while the impulse was calculated as the area under the same curve. For tests that led to failure, the impulse was calculated up to the point of failure of the anchors while for tests where the anchor did not fail, the impulse was calculated for the entire duration of the tension load. Figure 5a and Figure 5b illustrate typical behaviour anchors suffering no failure or failure, respectively.

Figure 6a shows a residual displacement after maximum displacement was reached, indicating the anchor resisted the full impact load. Figure 5b however shows a continuously increasing displacement, signifying complete failure of the anchor.

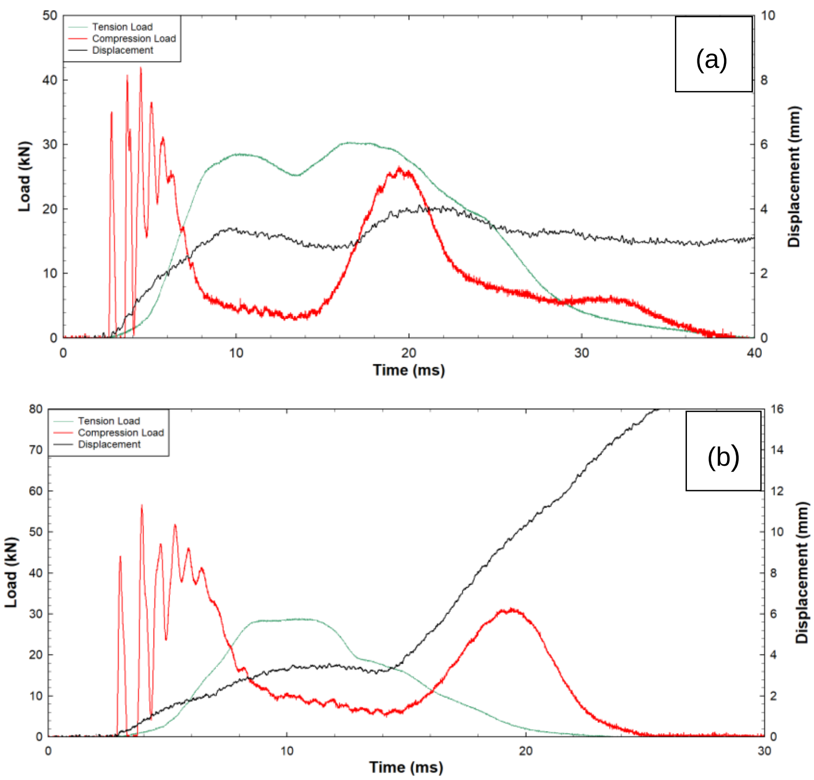


Figure 5: Typical Load profile for impact test: a) Sample did not fail; b) Sample failed

Tension tests

The failure mode observed in all cases of the experimental tension tests was mixed mode of anchor pullout and concrete cone breakout. The average failure cone angles measured were 28°, 27° and 21° respectively for the 6.4-, 9.5-, and 12.7-mm diameter anchors. The peak loads in each test was compared with the average static failure load to obtain a dynamic load ratio (DLR) defined as the ratio of the peak load to the static failure load of the anchor.

Figure 6 presents the DLR versus anchor diameter under tension drop-mass testing. For the 6.4-mm diameter anchor, the minimum DLR causing failure was 1.1 while the maximum DLR that did not result in failure was 1.5. For the 9.5-mm diameter anchors a DLR as high as 1.6 did not cause failure. For the 12.7-mm diameter anchor the minimum DLR causing failure of the anchorage system was 1.1 while the maximum DLR that did not result in failure was 1.4.

The dynamic increase factor (DIF) of the anchors was defined as the minimum DLR causing failure of the anchor or the highest DLR resulting in no failure of the anchor. Thus, from the foregoing, a DIF of 1.1 is recommended for 6.4-mm diameter anchors under tensile drop-mass testing. The DIF for the 9.5-mm and 12.7-mm diameter anchors were 1.5 and 1.1, respectively.

The 6.4-mm diameter anchors sustained impulses of up to 542 kN.ms before failing while the 9.5-mm and 12.7-mm diameter anchors sustained impulses of up to 893 kN.ms and 1128 kN.ms respectively.

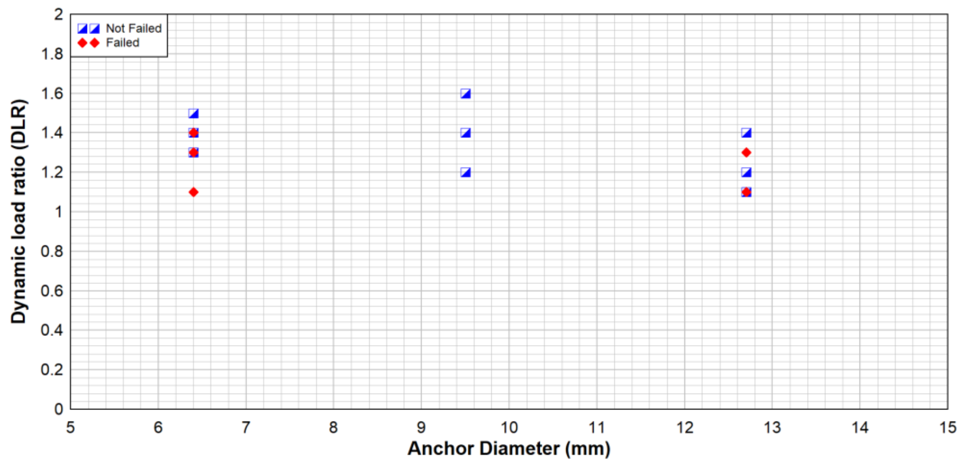


Figure 6: Dynamic load ratio against anchor diameter for tension test

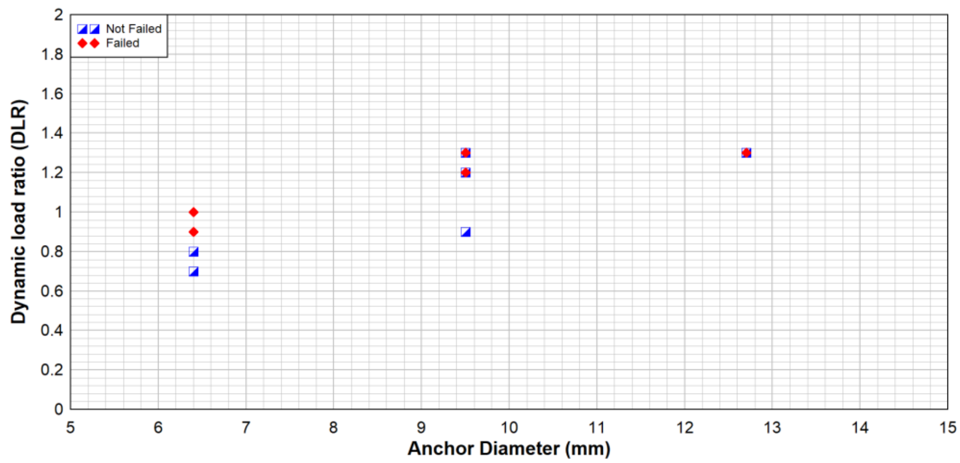


Figure 7: Dynamic load ratio against anchor diameter for shear test

Shear tests

Figure 7 presents the DLR versus anchor diameter under shear loading and shows the behavior of the anchors under dynamic shear loading. For the 6.4-mm diameter anchors, the minimum peak load that resulted in failure was associated with a DLR of 0.9 while the maximum impact load that did not result in failure had an associated DLR of 0.8. For the 9.5-mm diameter anchors, DLR of up to 1.3 did not result in failure, while a minimum DLR causing failure of the anchor was 1.1. The maximum DLR that did not result in failure of the 12.7-mm diameter anchor was 1.3 while the minimum DLR that resulted in failure was 1.2.

The recommended DIF of the 6.4-mm diameter anchor was 0.8 while for the 9.5-mm and 12.7-mm diameter anchor the recommended DIF under shear loading is 1.1 and 1.2, respectively.

6 Conclusions and recommendations

The experimental test program presented in this paper investigated the behavior of Titen HD® screw anchors under drop-mass testing. The test results show that the static and dynamic failure modes was a mixed anchor pullout and concrete breakout cone failure mode. This is contrary to what was predicted with the CCD method. The experimental static failure modes were consistently higher than the CCD predicted failure loads except for the 6.4-mm diameter anchor where the CCD method predicted steel anchor fracture instead of concrete breakout cone failure mode. For shear loading, all the anchors failed in the steel fracture failure mode, consistent with the predictions of the CCD method.

In general, the dynamic tests resulted in higher peak failure loads compared with the static failure loads, except for 6.4-mm diameter anchor under drop-mass shear loading. For tensile loading, the DIF greater than 1.0 was achieved for all three anchors diameters. This is consistent with reports by Braimah et al. (Braimah, Contestabile, and Guilbeault 2009) and Ahmed and Braimah (Ahmed and Braimah 2017) for adhesive and undercut anchors, respectively. The recommended DIF for impulse type tension loading from the test program reported in this paper are1.1, 1.5, and 1.1 for the 6.4-mm, 9.5-mm, and 12.7-mm diameter anchors, respectively. The DIF for the anchors under impulse type shear loading were 0.8, 1.1, and 1.2 for the 6.4-mm, 9.5-mm, and 12.7-mm diameter anchors, respectively.

Acknowledgement

The research reported in this paper was supported by material donation from Simpson Strong-Tie Canada and financial support from Natural Sciences and Engineering Research Council (NSERC), Canada.

References

ACI Committee 318. 2008. *Building Code Requirements for Structural Concrete (ACI 318-08)*. *American Concrete Institute*. https://doi.org/10.1016/0262-5075(85)90032-6.

ACI Committee 355. 2007. *ACI 355.2-07 Qualification of Post-Installed Mechanical Anchors in Concrete & Commentary*.

Ahmed, Lenda T., and Abass Braimah. 2017. "Behaviour of Undercut Anchors Subjected to High Strain Rate Loading." *Procedia Engineering* 210: 326–33. https://doi.org/10.1016/j.proeng.2017.11.084.

ASTM. 2010. "Standard Test Method for Drop Impact Resistance of Blow-Molded Thermoplastic," 1–6. https://doi.org/10.1520/D2463-10.2.

———. 2015. "E488 - Standard Test Methods for Strength of Anchors in Concrete Elements." *Astm* i: 1–21. https://doi.org/10.1520/E0488.

Bažant, Zdeněk P., Jin-Keun Kim, and Phillip A. Pfeiffer. 1986. "Nonlinear Fracture Properties from Size Effect Tests." *Journal of Structural Engineering* 112 (2): 289–307. https://doi.org/10.1061/(ASCE)0733-9445(1986)112:2(289).

Bischoff, P. H., and S. H. Perry. 1991. "Compressive Behaviour of Concrete at High Strain Rates." *Materials and Structures* 24 (6): 425–50. https://doi.org/10.1007/BF02472016.

Braimah, Abass, Ettore Contestabile, and Rick Guilbeault. 2009. "Behaviour of Adhesive Steel Anchors under Impulse-Type Loading." *Canadian Journal of Civil Engineering* 36 (11): 1835–47. https://doi.org/10.1139/L09-084.

C. Allen Ross. 1989. "Split-Hopkinson Pressure Bar Tests," 88.

CSA (Canadian Standards Association). 2014. "Design of Concrete Structures." *CAN/CSA S23.3- 14*. https://doi.org/10.1007/BF02479623.

Fu, By H C, M A Erki, and M Seckin. 1991. “Review o f Effects of Loading Rate on Reinforced Concrete. Tech. Rep. No. R642, U.S. Naval Civ. Engrg. Lab., Calif.” *Journal of Structural Engineering* 117 (12): 3660–79.

Fuchs, Werner, Rolf Eligehausen, and John E. Breen. 1995. “Concrete Capacity Design (CCD) Approach for Fastening to Concrete.” *ACI Structural Journal*. https://doi.org/10.14359/1533.

ICC Evaluation Services. 2009. “Acceptance Criteria for Mechanical Anchors in Concrete.”

Kuenzlen, Jurgen; Sippel, Thomas. 2001. “Behaviour and Design of Fastenings with Concrete Screws.” *International Simposium on Connections between Concrete and Steel* 1: 919–29.

Kuenzlen, J.H. 2004. “Load-Bearing Behaviour of Screw Anchors under Axial Tension.” University of Stuttgart.

Mallonee, Sue, Sheryll Shariat, Gail Stennies, Rick Waxweiler, David Hogan, and Fred Jordan. 1996. “Physical Injuries Resulting From the Oklahoma City Bombing.” *JAMA* 276 (5): 382–287.

Malvar, L Javier, and John E Crawford. 1998a. “Dynamic Increase Factors.” *28th DDESB Seminar Orlando*, 1–17.

———. 1998b. “Dynamic Increase Factors for Steel Reinforcing Bars.” *Proceedings of the Twenty-Eighth DoD Explosives Safety Seminar*, 1–18. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000971.

Norville, By H Scott, and Edward J Conrath. 2001. “Consideration for Blast -Resistant Glazing Design.” *Journal of Architectural Engineering* 7 (September): 80–86.

Olsen, Jacob, Thilo Pregartner, and Anthony J. Lamanna. 2012. “Basis for Screw Anchors in Concrete_ACI Jour..Pdf.” *ACI Structural Journal* July-Augus (109).

Rodriguez, M., D. Lotze, J. H. Gross, Y. G. Zhang, R. E. Klingner, and H. L. Graves. 2001. “Dynamic Behavior of Tensile Anchors to Concrete.” *ACI Structural Journal* 98 (4): 511–24.

Sato, Hiroshi, Kazunori Fujikake, and Sidney Mindess. 2004. “Study on Dynamic Pullout Strength of Anchors Based on Failure Modes.” *13th World Conference on Earthquake Engineering*, no. 854: 1–7.

Solomos, George, and Mario Berra. 2006. “Testing of Anchorages in Concrete under Dynamic Tensile Loading.” *Materials and Structures/Materiaux et Constructions* 39 (291): 695–706. https://doi.org/10.1617/s11527-006-9112-1.

Strong-tie, Simpson. n.d. “New Titen HD Screw Anchor,” no. 800.