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Cast – in anchor channels used to support curtain wall facades – numerical study of additional anchor reinforcement

Oana Ciascaiu[1], Tudor Panfil Toader [1,2], Călin G.R.Mircea[2], Andreea Hegyi[1]*

[2]NIRD URBAN-INCERC, Cluj-Napoca Branch, 400524 Calea Florești 117, Cluj-Napoca, Romania
[1]Technical University of Cluj-Napoca, Civil Engineering Faculty, 400020 Daicoviciu 15, Cluj-Napoca, Romania

Abstract. As the architectural trend for ever greater spans for glass framing elements keeps its momentum, we are dealing with larger reaction loads onto the elements connecting these to the concrete slab, respectively onto the anchoring system. Therefore, this numerical study has the scope of researching the use of standard cast-in anchor channels, commonly used to support curtain wall façade systems, that are positioned and cast-in relatively close to the edge of the reinforced concrete slab; as well as researching the evolution of the relationship between the concrete strength, slab thickness, anchorage length, the distances between the anchors, the T-bolt positioning, (lever arm of shear force on t-bolt), and the geometry of the "ski plates". Whilst many studies have been performed regarding the performance of both the concrete and these fastening systems, there is not sufficient information/classification relating to the influence of the welded "skis ", and as to what the optimal sizes and geometries are, when used in a class of concrete where this is critical. The main conclusion desired to be achieved is to find the optimal reinforcement plate (ski) shape and position for the given concrete and anchorage depth, allowing for a more accurate connection design, and to provide options for the instances where clashes occur.

1 Introduction

Anchor channels are an innovative and versatile fastening system, that has been used for over 100 years. They have first been approved in October 2010 under the AC232 Test Programs, used to establish the structural performance of anchor channel systems under static loads, wind loads and seismic loads. Mainly used in construction of buildings, their role is to fasten elements to concrete structures.

Anchoring systems meet the requirements of a wide variety of fixing needs, especially those related to important loads, as they absorb vertical tensile and shear loads. They range from simple self-anchoring slots for accepting restraint fixings, to large capacity channels with integral anchors. For curtain wall facades in particular, they provide the necessary adjustment required when fixing to concrete, and can eliminate site drilling, allowing for a more efficient installation process [1].

The focus within the content of this paper, is the tension resistance of channel anchors with a simple head at the ends, compared to enlarged plates, and the strength support that these types of reinforcements bring to the joint. This constitutes a preliminary study, scoping further potential analysis and studies in this direction.

The current technical specification tends to be under-estimative with regard to the capacity of specific arrangements of cast-in anchors **[2]**, such as channel-anchors. It has been shown in the literature that, at shallow embedment distances, we are encountering challenges with regards to the breakout of the concrete, which is contradictory to the ductile design philosophy which is referred to in greater detail below. Therefore, adding a plate to the end of the cast-in Anchors is an obvious option to overcome this issue. However, studies with regards to adding these plates are rarely available. [3] A study conducted by Yang and Ashour [4] has demonstrated that the concrete breakout capacity is directly linked to the size of the anchor head, therefore, this justifies the endeavour.

Further studies have been performed [5] [6], showing that in addition to the size and embedment distance, the shape of the plate constitutes a significant parameter that influences performance. An analytical approach for use of end plates has been studied and detailed for thin concrete panels, where the prevailing failure mode is the concrete cone failure, due to the limited embedment depth [7] [8]. Whilst the method is comparable and adaptable to the cast-in channels used in structural concrete slabs, the concrete cone failure is not preferred or desired if it can be avoided. It is better to follow the ductility principle, which sets precedence to the failure of the anchor-channel steel, to any plastic failure in the concrete.

As the Standards development progressed, provisions for ductile behaviour have been included, meaning that the tensile strength of an anchor will be less or equal to the tensile strength of an idealised concrete cone section. The design philosophy of this type of anchor relies on the principle that the embedded anchor or the channel profile will fail prior to the concrete, therefore establishing ductility as a driving design parameter, as avoiding concrete cracking or failure is key, particularly for buildings of high importance class.[5] [6][9]

There are two general procedures for determining the brittle failure. The first one, proposed by Courtois in

* Corresponding author: oanaciascaiu@gmail.com

1969 [10] considers a conical volume, determined by the projection, at 45 degrees of the anchor head surface. Drawing from the experimental results data, it has been established in practice that a conservative value of 8 to 10 times the anchor shank diameter to be used as embedment depth, will be sufficient for the concrete capacity to become greater than the anchor strength. In 1995, Fuchs [11] proposes the second determination method, considering a square base pyramid failure volume, projecting the faces at 35 degrees. Most current standards have withheld this method.

It is significant to mention the extensive amount of tests that have been performed by Bode and Roik in 1987 [12] (105 experiments) and Cook in 1995 (178 experiments) [13] which have highlighted a more realistic formula that can predict the tensile strength of headed anchors.

$$N_{b,avg} = 10.96\sqrt{h_{ef}}\,(h_{ef} + d_h)\sqrt{f_c'}\ \text{(N,mm)} \qquad (1)$$

Aside from the ductility philosophy parameters, it is vital to assess a precise behaviour of the concrete volume surrounding the cast-in channel. To this extent, in the analytical assessment of anchor plates, the scientific literature adopts the CC- design method (i.e. Concrete Capacity design), which is based on the assumption that all anchors of a group are loaded uniformly and can be determined by the theory of elasticity, with the further assumption that the end plates have infinite stiffness.[14],[15][16]

The component method, initially developed for steel joints, has been applied to steel to concrete joints in a research document that came from a European project of 2012, focused on development of mechanical models, named "Innovative Fastening Solutions between Steel and Concrete" (INFASO). This method considers the joint to be formed of individual separate components which each contribute to its structural behaviour from the point of view of resistance, stiffness, and ductility. [17][18].

Fig. 1. Cast-in Anchor Channel / CW Bracket Connection [https://www.halfen.com/us/3226/product-ranges/construction/anchoring-systems/hcw-curtain-wall-system/introduction/…]

Fig. 2. Cast-in Anchor Channels Connecting the Curtain wall brackets to the concrete slab [https://www.halfen.com/us/3226/product-ranges/construction/anchoring-systems/hcw-curtain-wall-system/introduction/].

1.1 Anchor Channel Systems

These anchor channel–channel bolt-systems can take up high tension loads (N in z-direction) and shear loads (V in x- and y-direction) by mechanical interlock, making the system very robust and even suitable to withstand explosive loads, seismic loads, and fatigue loads [18].

Installation Method	Description
 a)	The anchor channel is positioned either to the timber form work with nails through prefabricated holes, or directly to the reinforcement bar, by wire binding.
 b)	During casting, the concrete needs to be well compacted around channel and anchors, and underneath the anchor heads.
 c)	Once the concrete is cured, the foam protection is removed from the channel with a hammer or hook

Fig. 3. Positioning and casting into concrete of Anchor Channels [21].

The possibility of fixing the channel bolts at any location along the length of the channel offers higher flexibility to the designer than other cast-in systems such as baseplates [20].

For the adequate installation of anchor channels, it is required that an appropriately qualified person carries out the process, whilst being supervised by the responsible person. The process needs to be implemented following the installation instructions given by the manufacturer, without any manipulation, repositioning or exchanging of channel components.

The T-bolt is inserted into the channel and twisted 90 degrees clockwise, such that it engages into the channel. (Fig. d). The bolts can be slid into position, the minimum edge clearance for the T-bolt at channel ends being 35mm.

The installation torque for general application must be 60 (Nm), and, in the case of steel to steel contact, 200 (Nm). The installation Torque must not be exceeded [21][22].

1.2 Loads on Facades

Generally, the critical and design-driving loads for facades are wind and dead load. As most studies have been performed on simple façade and building geometries, resulting in a very limited available guidance, and given the evermore atypical geometries required by architects, the facades industry very often has to refer to computational fluid dynamics CFD wind simulations [23] , wind-tunnel tests, and large scale mock-up Tests. This holds great importance, as there is no applicable guidance accounting for oblique flow, and effects on façade features such as louvres, brise-soleil, protruding fins, and other architectural elements, functional or decorative.

These loaded elements can bring a significant increase in loads transmitted onto the brackets and onto the concrete slab, via the anchor channel connection.

1.3 Failure Modes

Depending on material properties, geometries and loads, there are several modes in which these assemblies can fail. As highlighted before, as a function of the above parameters, we may encounter failure of steel, failure of weld of connection, or failure of the concrete embedment, when the minimum of either pull out strength or break out strength is reached before reaching the steel strength.

The steel failure from tension can occur at anchor-channel connection (Fig. 5.), anchor failure (Fig. 6.), or more commonly at the channel lip (Fig. 4.).

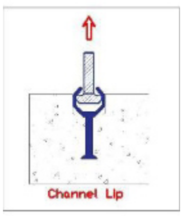


Fig. 4. Channel Lip

Fig. 5. Anchor and Channel connection

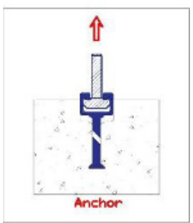


Fig. 6. Anchor

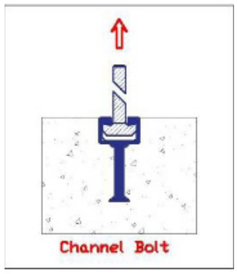


Fig. 7. Channel Bolt

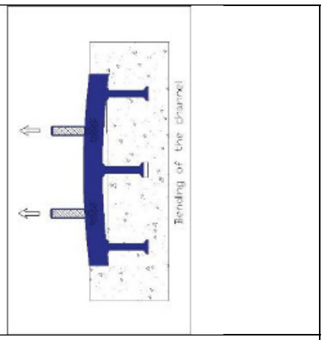


Fig. 8. Bending of the channel

More rarely, we can encounter a failure of the T-bolt (Fig.7), or a bending of the channel (Fig.8) driving the pull-out.

Lateral shear causes the flexural bending of the channel to occur through bending of the T-bolt, or causes the connection between the channel and anchor to fail, or furthermore, causes the T-bolt itself to section. See Fig. 9. , Fig. 10.,and Fig. 11. [15]

Fig. 9. Channel lip

Fig. 10. Anchor and Channel connection

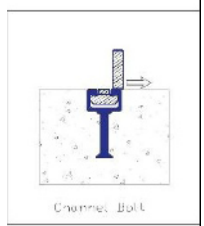


Fig. 11. Channel Bolt

The concrete failure will be driven by parameters like concrete resistance properties, edge proximity [22]. corners, effects of neighbouring anchors, concrete shell spalling, or other hygric deformations at boundaries. These will result, under tension loading, in either pull-out (Fig. 12.), blow-out (Fig. 13.) or cone break out (Fig. 14.).

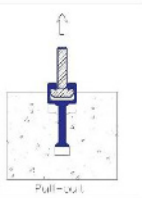


Fig. 12. Pull out

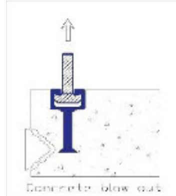


Fig.13. blow-out

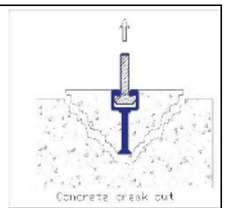


Fig. 14. Concrete break out

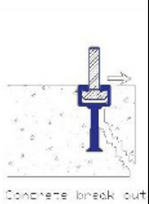


Fig. 15. Break out

Fig.16. Pry-out

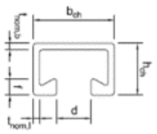
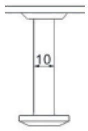
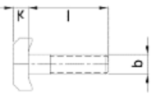
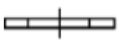
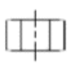
Under lateral shear, depending on edge distance, the concrete will break out laterally (Fig. 15**.**), or the anchor will pry-out .(Fig.16)

2 Experimental method – materials and method

2.1 Materials

Anchor channels may only be used in structures subject to dry internal conditions. They can also be used in exceptional internal conditions with the usual humidity with the following provisions:

Table 1. Anchor Channel Assembly

Specification	**Materials – (1). Dry Internal Conditions (e.g. residential, commercial buildings, schools, hospitals etc)**
	(2). Usual Humidity Internal Conditions (eg. Kitchen, bath and laundry , exceptional permanent damp conditions)
Channel Profile 	(1). Steel Q235 Acc. To GB/T 700-2006 Hot-dip galv. >100µm
	(2). Steel Q235 Acc. To GB/T 700-2006 Hot-dip galv. >100µm
Anchor 	(1). Steel Q235 Acc. To GB/T 700-2006, BG/T 14981-2009 Hot-dip galv. ≥100µm
	(2). Steel Q235 Acc. To GB/T 700-2006, BG/T 14981-2009 Hot-dip galv. ≥100µm
Channel Bolts according to EN ISO 4018 	(1). Strength grade 8.8 Acc. To EN ISO 898-1 Electroplated ≥5 µm
	(2). Strength grade 8.8 Acc. To EN ISO 898-1 Hot dip galv. ≥50 µm
Washer according to DIN 125 	(1).Referring to EN 10025 electroplated ≥5µm
	(2). Referring to EN 10025 electroplated ≥50µm
Hexagonal nuts according to DIN 934 	(1). Strength grade 8.8 acc. To EN ISO 20898-2 Electroplated ≥5µm
	(2). Strength grade 8.8 acc. To EN ISO 20898-2 Electroplated ≥50µm

As a base material, we use an unreinforced normal weight concrete according to EN 206-1:2000, Strength Class C20/25 according to EN 206-1:2000 [24], cracked.

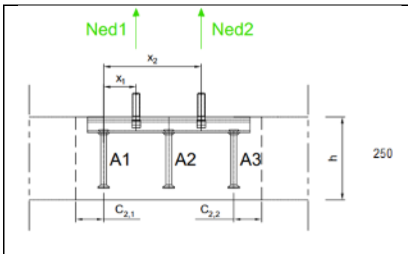


Fig. 17. Anchor Channel Assembly

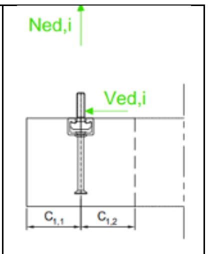


Fig. 18. Side View

2.1.1Analytical evaluation

The main loads that are applied onto the studied assembly are generated by wind and dead load.

The industry uses common practices that are in line with EN 1992-4:2018**[24]**, which provides a design method for fastenings that are used to transmit actions to the concrete, in particular connection of structural elements and non-structural elements to structural elements. As specified in the standard, this design method uses physical models which are based on a combination of tests and numerical analysis consistent with EN 1990:2002 [25], 5.2. This covers steel inserts embedded in concrete.

In conjunction with this, and for the lack of other extensive methods, we use the European Technical Assessments (ETA) from the manufacturer's approved test assessment.

A series of checks is performed for each of the assembly elements:

2.1.2 Tension Checks:

1 On T-bolt

$N_{Rd}=N_{Rk}/g_M$ .... (2)

where the Partial Safety Factor for special screw is $\mathbf{g}_{Ms=}1.5$;

And where $N_{Rk} = A_s \times f_{uk}$ [MPa] (3)

2 On Anchor

$N_{Rd} = N_{Rk} /g_M$ (4)

where the Partial Safety Factor for anchor is $\mathbf{g}_{Ms=}1.8$;
And where $N_{Rk} = A_s \times f_{uk}$ [MPa] (5)

3 On Channel Lips Capacity
$N_{Rd}=N_{Rk}/\mathbf{g}_M$ (6)

where the Partial Safety Factor for channel is $\mathbf{g}_{Ms=}1.8$;

4 On Anchor/Channel Connection

$N_{Rd}=N_{Rk}/\mathbf{g}_{Mcnx}$ (7)

where the Partial Safety Factor for channel is $\mathbf{g}_{Mcnx=}1.8$;

5 Concrete Capacity

6 Pull-out failure

$$N_{Rd}=N_{Rk}/g_{Mc} \quad (8)$$

where the Partial Safety Factor for concrete is $g_{Mc=}1.5$

7 Concrete Cone failure

Basic Characteristic resistance for one anchor

$$N^0_{Rk,c} = k_1 \cdot (f_{ck})^{0.5} \cdot h_{ef}^{\ 1.5} \quad (9)$$

Where k_1 is $k_{cr,N}$, (cracked concrete) or $k_{ucr,N}$, (uncracked concrete)

$$N_{Rk,c} = N_{0Rk,c} \cdot \Psi_{ch,s,N} \cdot \Psi_{ch,e,N} \cdot \Psi_{ch,c,N} \cdot \Psi_{re,N} \quad (10)$$

$$N_{Rd,c} = N_{Rk,c} / \gamma_{Mc} \quad (11)$$

2.2.2 Shear Checks

1 On T-bolt

$$V_{Rd} = V_{Rk,s,s} /g_{Ms} \quad (12)$$

where the Partial Safety Factor for special screw is $g_{Ms=}1.25$

And where $N_{Rk} = A_s \times f_{uk}$ [MPa] (13)

2 On Channel Lips Capacity (Flexure)

$$V_{Rd,S,l}=V_{Rk,s,l}/g_{Ms,l} \quad (14)$$

where the Partial Safety Factor for the channel lips is $g_{Msl=}1.8$.

3 Concrete Capacity
3.1 Concrete Edge failure
3.2

$$V_{Rk,c} = k_{12} \cdot (f_{ck})^{0.5} \cdot c^{14/3} \quad (15)$$

Where k_{12} (cracked concrete) = $k_{cr,V}$;
k_{12} (uncracked concrete) = $k_{ucr,V}$

3.3 Concrete Pry-out failure

$$V_{Rk,c} =V_{0Rk,c} \cdot \Psi_{ch,s,V} \cdot \Psi_{ch,c,V} \cdot \Psi_{ch,h,V} \cdot \Psi_{ch,90^\circ,V} \cdot \Psi_{re,V} \quad (16)$$

3 Results and discussions

3.1. Analytical Results

After performing all the tension checks for the standard Anchor channel cast in concrete Class C20/25, it is highlighted that the governing failure mode is the **concrete cone failure** under the middle Anchor (A2), at 99%. Concomitantly, the steel failure of the Anchor reaches 96% capacity.

$$N_{Rdc} = 17.34\text{kN} > N_2=17.32\text{kN} \quad (17)$$

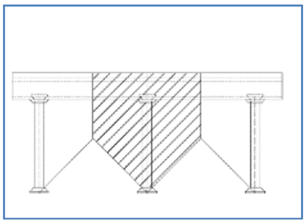


Fig. 19 Volume of concrete displacement corresponding to headed anchor.

Moving forward to the plated version, we proceed with adjusting within the

$$N_{0Rk,c} = k1 \cdot (fck)^{0.5} \cdot hef^{1.5} \quad (18)$$

formula, the area of displacement of the concrete with the new $h_{effective}$ value of 172mm, generated by the projection at 45% of the plates edges, and we therefore obtain an increased value for tension resistance.

$$N_{Rdc} = 20.02\text{kN} > N_2=17.32\text{kN} \quad (19)$$

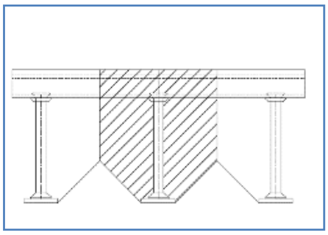


Fig. 20. Area of concrete displacement corresponding to headed anchor with additional plates.

This represents an improvement of **16.49%** in capacity for this area.

There is no significant change in tension values for the T-bolt, Channel Lip or Channel/Anchor connection Stress Values.

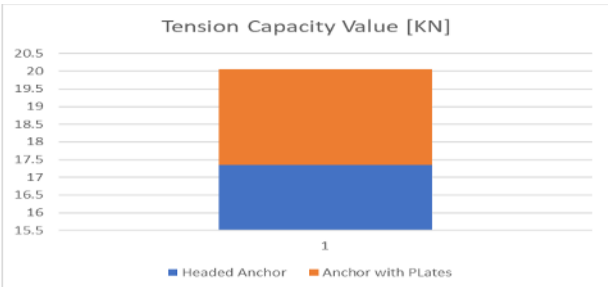


Fig. 21. Tension Capacity Comparison, Headed Anchor vs. headed anchor with additional plates.

3.2. Numerical Evaluation

A set of finite element (FE) models was prepared in order to simulate the behaviour of the anchor channel system and to check and compare results between the simple headed anchor option and the welded plates option. Abaqus FEA finite element software was adopted.

A group of FE models was created by modelling the steel components of the connection, and a concrete block, in which the fastening system is embedded, and is aimed to validate the simplified models and check the stress fields within the Steel Anchor Channel Assembly, in

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critical failure areas, such as Channel Lip, channel/anchor connection, Anchor head, as well as in the C20/25 Concrete block. For both versions of the anchor channel FE models, the same bolting system has been modelled, this being the traditional T-head bolt. The Anchor Channel has been positioned at 110mm from the edge of the concrete (as per industry minimum slab edge specification).

The bolts were positioned at mid-span between the anchor positions and have been loaded in tension with 20kN per bolt. We have therefore obtained a series of Stress results as per the figures below.

Standard Anchor

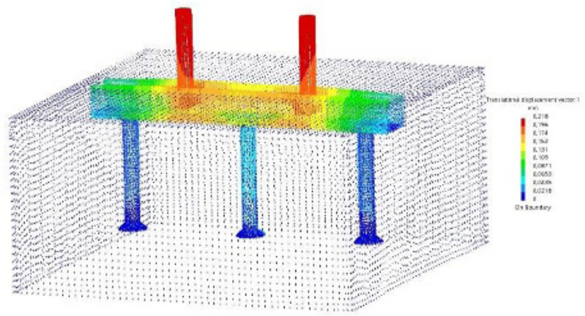

Fig. 22. Global VM Stress on boundary

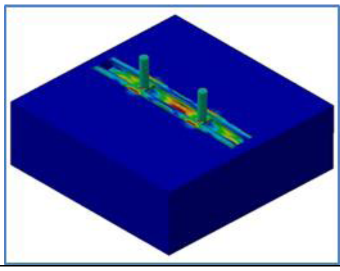

Fig. 23. Stress Gradient and Displacement at Channel

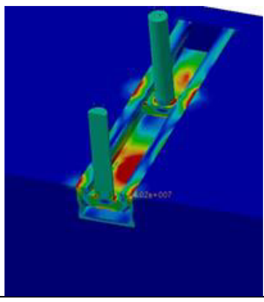

Fig. 24. Stress Gradient at T-bolt/Channel Lip

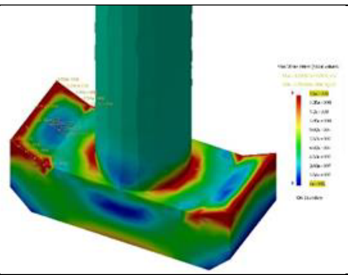

Fig. 25. Maximal stress on T-Bolt- **338MPa**

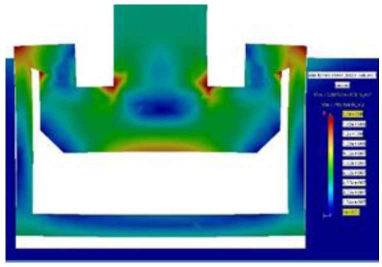

Fig. 26. Maximal stress at Channel Lip- **150MPa**

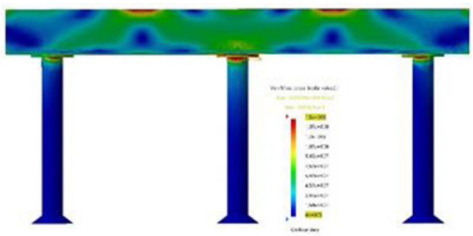

Fig. 27. Stress Gradient Anchor/Channel Connection

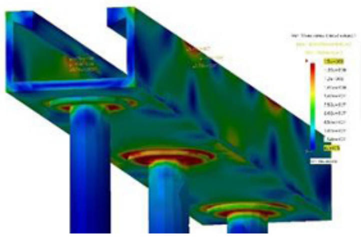

Fig. 28. Maximal stress Value at Anchor/Channel Connection – **304MPa**

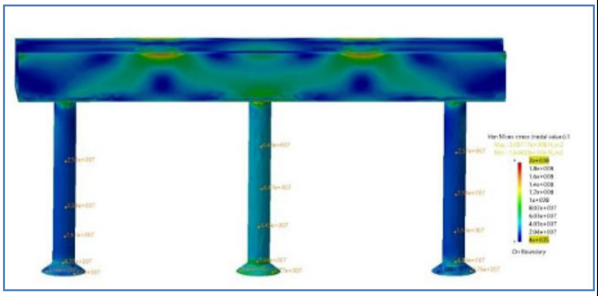

Fig.29. VM Stress Values on Anchor

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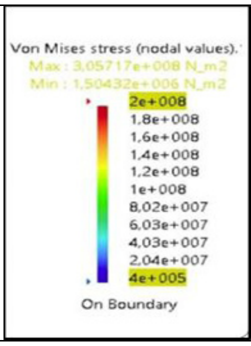

Fig. 30. VM Stress Values at Anchor

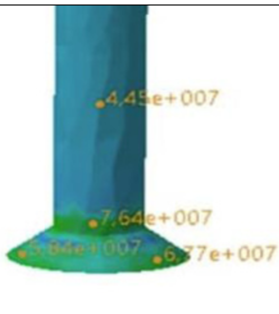

Fig. 31. Maximal stress at Anchor Head- **76.4MPa** . []

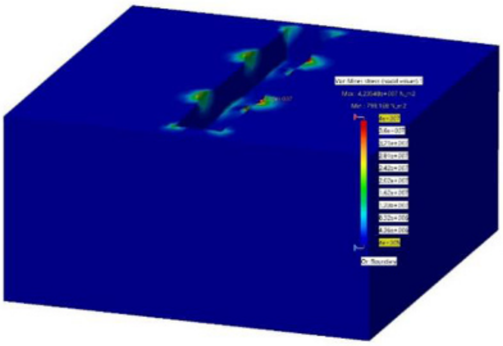

Fig.32. Maximal stress on Concrete -**33.9MPa**

Headed Anchor with Plates

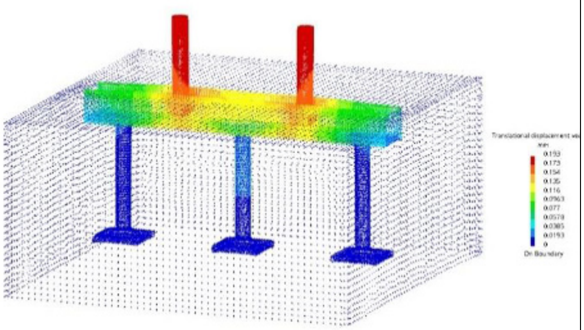

Fig. 33. Global VM Stress on boundary

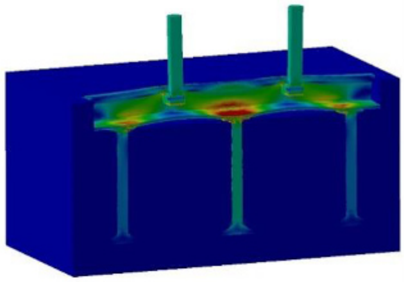

Fig. 34. Stress Gradient and Displacement at Channel

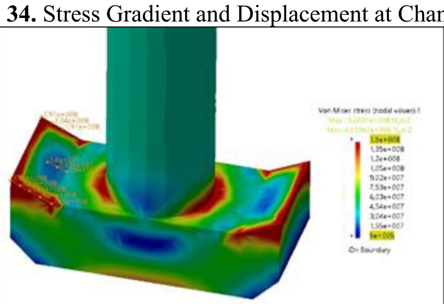

Fig. 35. Maximal stress on T-Bolt- **324MPa**

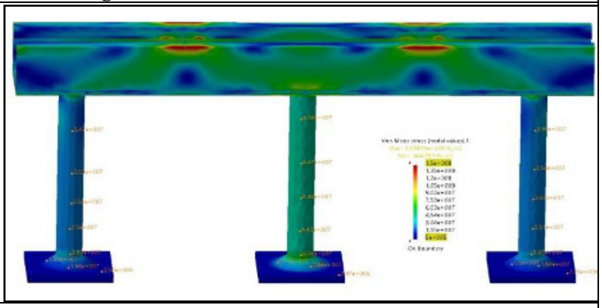

Fig. 36. Maximal stress at Channel Lip- **101MPa**

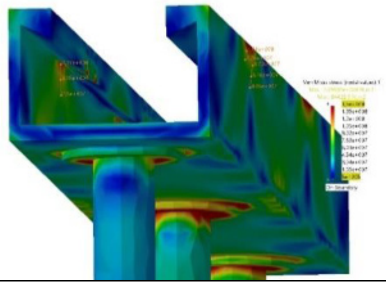

Fig. 37 Maximal stress Value at Anchor/Channel Connection – **269MPa**

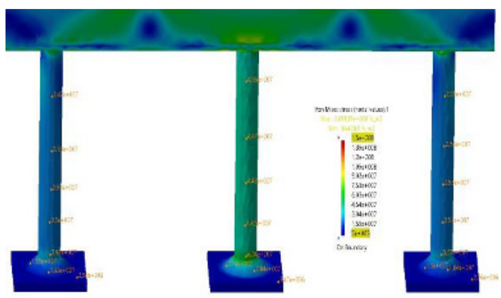

Fig. 38 VM Stress Values on Anchor. Max MM Stress: **269MPa**

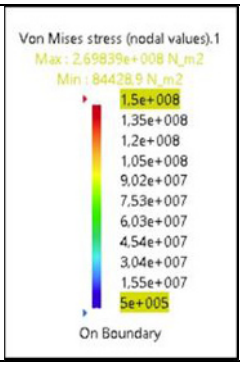

Fig. 39 VM Stress Values at Anchor

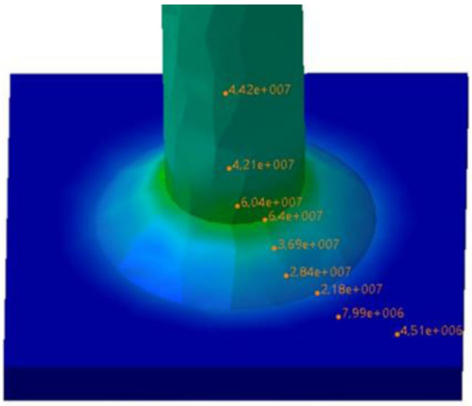

Fig. 40. Maximal stress at Anchor Head with welded plate-**64MPa**

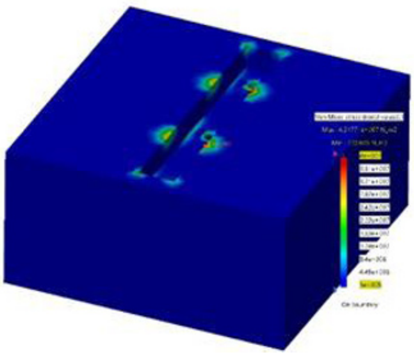

Fig. 41. Maximal stress on Concrete **-33.3MPa**

4 Comparative evaluation

As a result of the numerical analysis, we can compare the designated failure prone areas in terms of Stress. It may be concluded that for all areas there is a decrease in the Stress values exerted by the Steel assembly.

Given the critical failure mode being studied in this paper is the concrete cone failure, it results that the stress reduction in the Steel component will favour the stress capacity of the concrete cone.

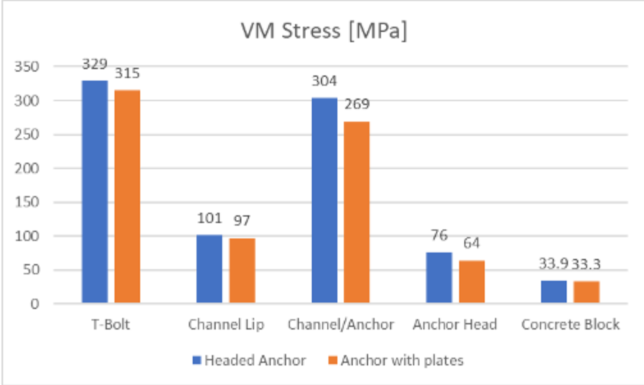

Fig. 42. Comparative Graphics for Stress Values at different zones.

It is therefore identified that the Stress Capacity for the given Load presents a percentual increase as pe the graph below.

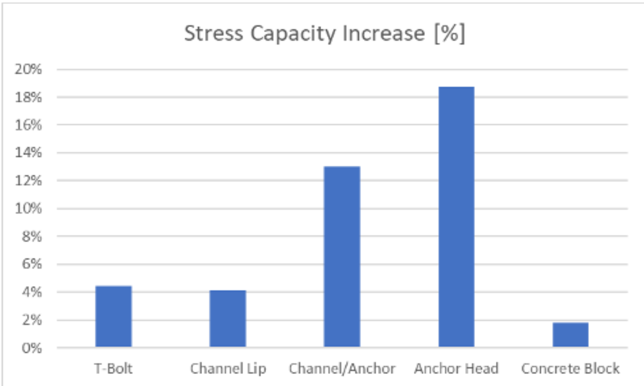

Fig.43. Percentual Stress Capacity increase for specified areas of Anchor Channel.

Focusing on the Anchor head area, where an analytical assessment has also been performed for both simple headed anchor and plated anchor, it is evidential that whilst the Numerical results predict an improvement in capacity of over 19%, the analytical predicts 16%.

4 Conclusions

The analytical study, compared to the numerical study is predicting a lower improvement of tension capacity for cone pull out from the concrete, underneath the most loaded anchor (i.e. middle anchor out of 3No. Anchors on the chosen Anchor Channel Type). Whilst the analytical calculation, set out in line with the ETA testing and EN 1992-4:2018 [24], predicts a 16% improvement, the numerical assessment, set out on the basis of an identical geometry and material model, subjected to identical tension loads applied on the T-bolts, predicts a 19% improvement from the simple anchor to the Anchors with 40x40x4mm plates added to the ends.

As for this model the performance change for the other studied areas such as T-Bolts or channel lip are negligible compared to the critical concrete cone failure or the channel/anchor connection, it is evident that we need to funnel the focus onto them, and endeavour to improve the performance in these areas.

This study represents the start of a series of analyses, in an analytical form, numerical and experimental, that will account for further parameter changes in terms of concrete properties and Anchor Channel Geometries, aiming to further the in-depth knowledge of the behaviour of this type of steel-concrete connection. In effect, this represents an endeavour to optimise the connection solutions between façade elements and the concrete structural supporting elements.

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