UNIVERSIDAD SAN FRANCISCO DE QUITO USFQ

Colegio de Ciencias e Ingenierías

STRIP MODEL FOR PREDICTING ECCENTRIC PUNCHING SHEAR CAPACITY OF REINFORCED CONCRETE SLABS

.

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RESUMEN

El modelo presentado, utiliza un puntal arqueado para describir la transferencia de corte en una losa de dos direcciones. Describe una ruta de carga antes de la falla que se puede adaptar a una amplia gama de losas bajo cargas puntuales, tanto concéntricas como excéntricas. El punzonamiento excéntrico puede ocurrir en conexiones de losa-columna sometidas a una combinación de esfuerzos cortantes y momentos desbalanceados. Normalmente, esta situación se produce en conexiones de losa-columna, situadas en columnas de borde y de esquina. Para este trabajo, se evalúa una base de datos de 35 experimentos de losa-columna. Las capacidades predichas por el modelo se comparan con la carga máxima en el experimento. Se destaca la importancia del desarrollo del refuerzo perpendicular al borde libre. Este trabajo muestra cómo se puede usar un modelo basado en los principios de la plasticidad de límite inferior para el caso práctico de la capacidad de una conexión para columnas de borde y esquina. Así mismo, el modelo puede utilizarse para fines de análisis como para situaciones de diseño

Palabras Clave: puntal arqueado, columnas, punzonamiento excéntrico, hormigón armado, losas, strip model.

ABSTRACT

The strip model makes use of an arched strut to describe shear transfer in a two-way slab. It describes a load path prior to failure that can be tailored to a wide range of slabs under concentrated loads, both concentric and eccentric. Eccentric punching shear can occur in concrete slab-column connections subjected to shear and unbalanced moments. Common practical cases are at edge and corner columns. For this work, a database of 35 edge and corner column-slab tests is evaluated. The predicted capacities using the strip model are compared to the maximum load in the experiment. The importance of development of reinforcement perpendicular to the free edge is highlighted. This work shows how a lower bound plasticity-based model can be used for the practical case of the slab-column capacity for edge and corner columns, both for analysis and design situations.

Keywords**:** arched strut, columns, eccentric punching shear, reinforced concrete, slabs, strip model

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STRIP MODEL FOR PREDICTING ECCENTRIC PUNCHING SHEAR CAPACITY OF REINFORCED CONCRETE SLABS

Bernardo Carrera, Eva O.L. Lantsoght and Scott D.B. Alexander

SYNOPSIS

The strip model makes use of an arched strut to describe shear transfer in a two-way slab. It describes a load path prior to failure that can be tailored to a wide range of slabs under concentrated loads, both concentric and eccentric. Eccentric punching shear can occur in concrete slab-column connections subjected to shear and unbalanced moments. Common practical cases are at edge and corner columns. For this work, a database of 22 edge and corner column-slab tests is evaluated. The predicted capacities using the strip model are compared to the maximum load in the experiment. The importance of development of reinforcement perpendicular to the free edge is highlighted. This work shows how a lower bound plasticity-based model can be used for the practical case of the slab-column capacity for edge and corner columns, both for analysis and design situations

Keywords: arched strut, columns, eccentric punching shear, reinforced concrete, slabs, strip model

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INTRODUCTION

A flat plate can be defined as a slab of uniform thickness supported on columns. Flat plates are usually used for relatively light loads, as occurring in apartments or similar structures. Flat slabs (which are flat plates without drop panels or capitals at the slab-column connection) are used for spans ranging from 5 m (15 ft) to 6 m (20 ft) and, among the widely used structural systems, they have presented effective and economical solutions in the construction of mid- and high-rise buildings [1]. In general, the design of flat plates is governed by serviceability limits regarding deflections or by the ultimate strength of the slab-column connection [2]. According to Oukaili and Husain [3], there are several factors that affect the strength of a slab-column connection such as the column size, concrete compressive strength, thickness of the slab and the flexural reinforcement ratio.

Usually, the ultimate strength of the slab-column connection is associated with two-way shear (punching failure) and it could lead to the progressive collapse of the structure. Once a punching shear failure has occurred, the load is transferred to the adjacent connections, possibly overloading them and causing them to fail as well. Because the load transfer from flat slabs to the columns is direct, the slab-column connection needs special attention because a failure of this type is both brittle and catastrophic. Hence, although a flat slab has large ductility for flexure, it possesses very little ductility when it comes to punching failure.

The behavior of a slab-column connection becomes complex in the presence of shear and unbalanced moments due to asymmetrical loading, unequal spans, structural discontinuity and the presence of lateral forces originating from wind or earthquakes [1]. In such cases, the shear distribution on the punching perimeter becomes asymmetrical and the capacity of the slab-column connection decreases. The analysis for these cases involves a combination of flexure, shear, and torsion in the slab-column connection. Because of this, failures can take various forms making the punching behavior less predictable. Common practical cases of eccentric punching shear occur at edge and corner columns.

RESEARCH SIGNIFICANCE

Most studies on punching shear are based on experiments on slab-column connections subjected to loads applied concentrically. Studies regarding eccentric punching shear are scarce and most of the existing codes present empirical methods that are inconsistent with the experimental data. Given the uncertainty on the eccentric punching shear capacity of slab-column connections, edge and corner columns often become governing for the design. We propose the use of the Strip Model to determine the capacity of slab-column connections subjected to eccentric punching shear, since the model can be easily adapted to different geometrical and loading conditions. This approach can reduce the uncertainties on predicting the capacity of slab-column connections.

LITERATURE REVIEW

Eccentric Punching Shear

Eccentric punching shear occurs in a slab-column connection in the presence of shear and unbalanced moments. This type of failure is more common in corner and edge columns. The punching provisions from ACI 318-19 [4] provide empirical equations and are based on the maximum shear stress v_u on the critical perimeter b_o of the slab-column connection assuming a distance of 0.5d from the face of the column to the perimeter. The ultimate shear stress v_u shall not exceed the nominal capacity of the slab v_n, which is a combination of the concrete shear strength v_c and the strength provided by shear reinforcement v_s, if any. Figure 1 shows a general sketch of the distribution of unbalanced moments in a typical slab-column connection. ACI 318-19 § 8.4.1.2 states the importance of considering unbalanced moments. MacGregor and Wight [1] define v_u as:

$$v_u = \frac{V_u}{b_o d} \pm \frac{\gamma_v M_{u1} c}{J_{c1}} + \frac{\gamma_v M_{u2} c}{J_{c2}} \qquad (1)$$

where V_u is the factored shear acting on the centroid of the critical section; c is the distance from the centroid of the critical section to the point where the shear stress is calculated; J_c is the polar moment of inertia of the critical section and $\gamma_v M_u$ is the fraction of factored moment transferred by eccentricity shear with γ_v as:

$$\gamma_v = 1 - \gamma_f \qquad (2)$$

Here, γ_f is the fraction of moment transmitted by flexure:

$$\gamma_f = \frac{1}{1+\left(\frac{2}{3}\right)\sqrt{\frac{b_1}{b_2}}} \quad (3)$$

Here b_1 is the total width of the critical section measured perpendicular to the axis about which the moment acts and b_2 is the total width parallel to the axis. Figures 1,2, 3 and 4 show the distribution of shear stress and unbalanced moment in a slab-column connection.

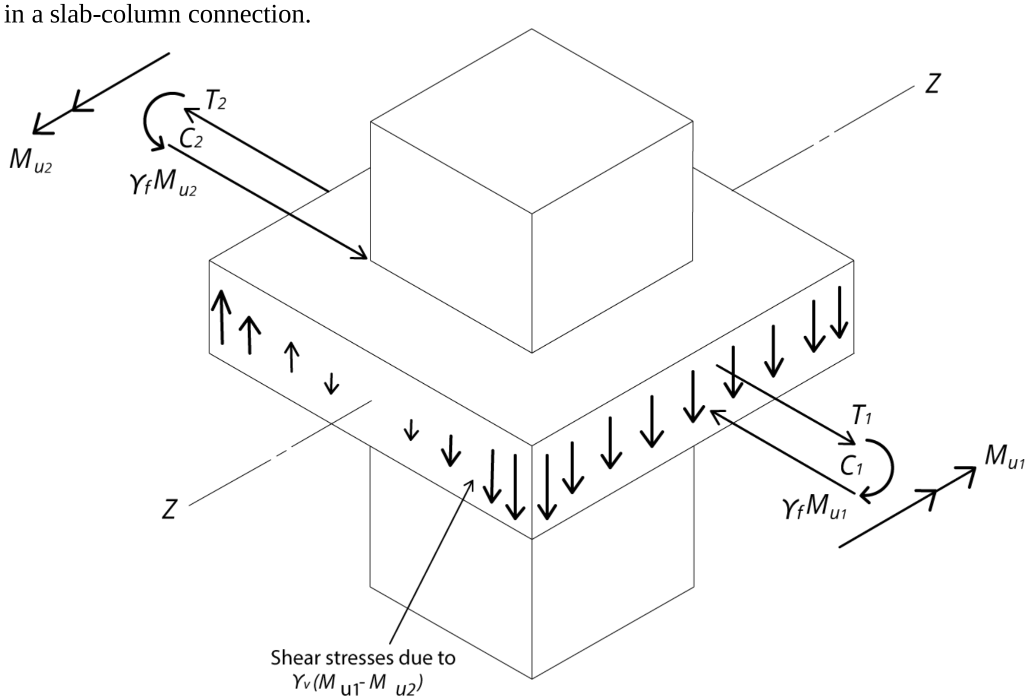

Figure 1: Transfer of unbalanced moments to column, modified from [1]

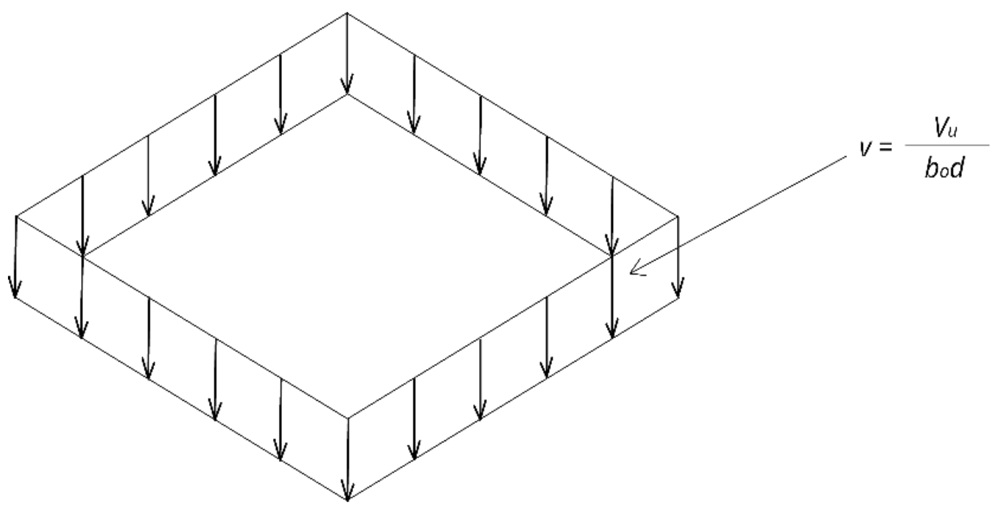

Figure 2: Shear stresses due to V_u, modified from [1]

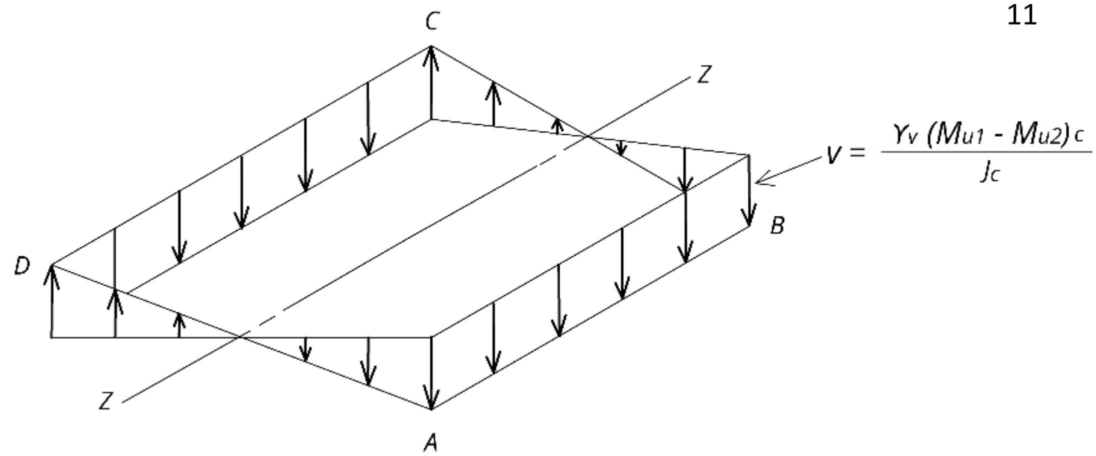

Figure 3: Shear stress due to unbalanced moment, modified from [1]

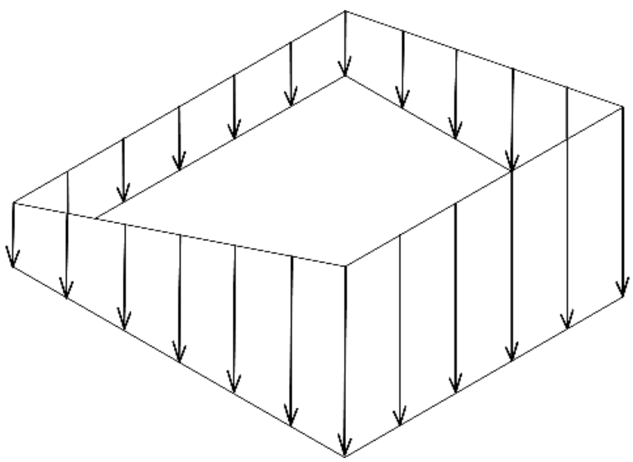

Figure 4: Total shear stress modified from [1]

ACI 421.3R-15 states that for slabs without beams, experience has shown that measures should be taken to resist the torsional and shear stresses [5]. In addition, a large degree of ductility is required because the interaction between shear and unbalanced moment is critical. Section 7.5 emphasizes that during earthquakes, significant horizontal displacements may occur, resulting in unbalanced moments and possibly generating a brittle punching shear failure. For these type of loading systems, ACI 421.2R-10 states that even when an independent lateral force system is provided, flat plate column connections should be designed to accommodate the moments and shear forces associated with the displacements during earthquakes [6]. All ACI references state the importance of unbalanced moments and consideration of detailing to ensure ductile behavior, however none of the references explain how this should be done.

NEN-EN 1992-1-1:2005 [7] provisions assume that the concrete contribution to the shear capacity is equal for one-way shear and two-way shear. As with the ACI 318-14 provisions, a perimeter b_o is established, but in this case, the perimeter is located at 2d from the loaded area and round corners are used. The punching capacity of the slab is based on the shear stress v_{Ed}

$$v_{Ed} = \beta_{ED} \frac{V_{Ed}}{b_o d} \tag{4}$$

$$\beta_{ED} = 1 + k_c \frac{M_{Ed}}{V_{Ed}} \frac{b_o}{W_1} \tag{5}$$

where W_1 represents the shear distribution on the perimeter, V_{Ed} is the design shear force, $M_{Ed}$is the design moment and $k_c$is a coefficient based on the ratio between column dimensions c_1/c_2. k_c increases as the column dimension, in the same direction as the unbalanced moment, increases. The coefficient is given by Table 6.1 from Eurocode 2 NEN-EN 1992-1-1:2005 [7].

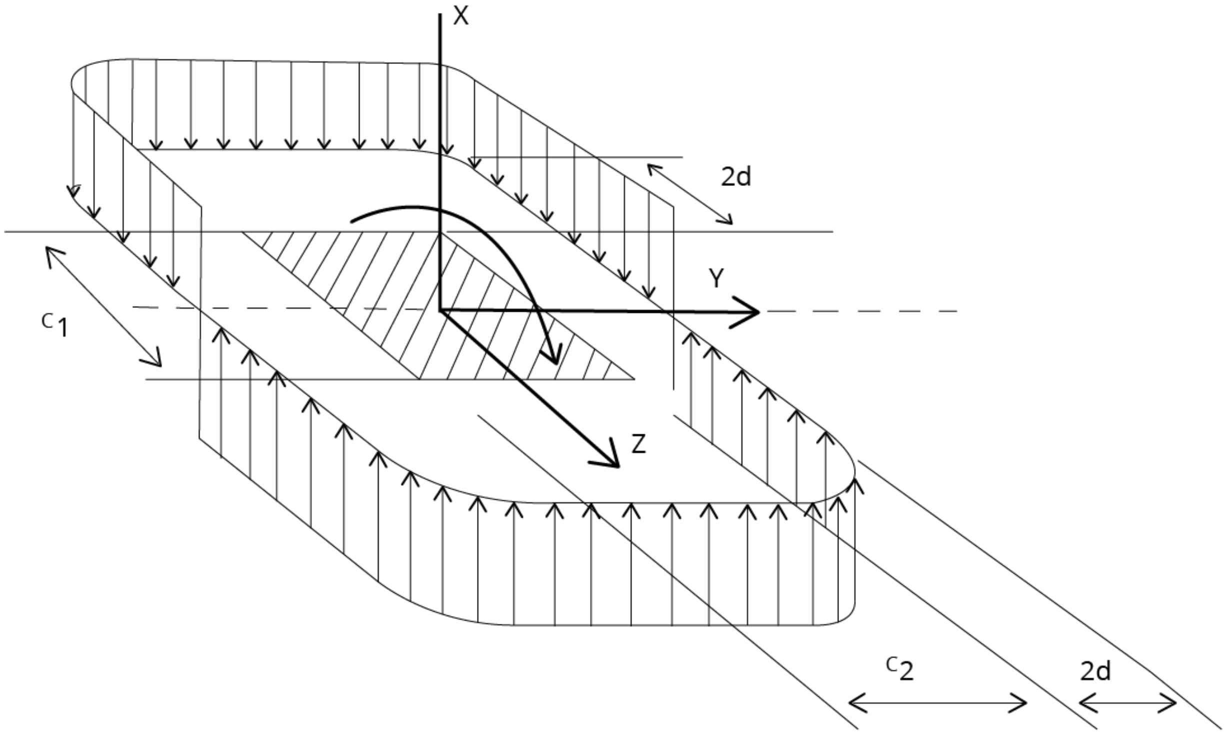

Figure 5: Shear distribution in a slab-column connection, modified from [7]

Shear Transfer in One-Way and Two-Way Flexural Systems

In a reinforced concrete flexural member, bending moment can be expressed as the product of the steel's tensile force *T*, and the internal lever arm *jd*. Conceptually, one-way shear can be defined as the gradient of bending moment along the length of the member. In other words, one-way shear (moment gradient) exists wherever the magnitude of the tensile force or effective moment arm varies along the length of the member [8].

$$V = \frac{d}{dx}M = \frac{d}{dx}\left(Tjd\right) = \frac{d\left(T\right)}{dx}jd + \frac{d\left(jd\right)}{dx}T \tag{6}$$

Shear resulting from a varying tensile force over a constant moment arm is known as beam action. Shear flow across any horizontal plane between the reinforcement and the compression zone needs to exist for beam action to be present and requires bond between the steel and concrete. On the other hand, arching action refers to the component of shear resulting from a constant tensile force on a varying moment arm. In this case, shear flow cannot be transferred because the steel is unbonded, or if the transfer of shear flow is interrupted by an inclined crack. Arching action requires anchorage of the reinforcement and its magnitude depends on the slope of the compression strut. Beam action is characteristic of slender flexural members known as B-regions and arching action is usually associated with deep beams known as D-regions.

In a two-way flexural system, shear can be transferred by bending shear and torsional shear. Bending shear is produced by a gradient in the bending moment as in one-way flexural systems and present characteristics of both B- and D-regions used in a strut-and-tie modeling. Torsional shear is produced by a gradient in the torsional moments and is a unique characteristic of two-way flexural systems. Many experiments for slab-column connections show that arching action is the dominant mechanism of shear transfer in the radial direction and strain measurements suggest an inclined radial compression strut rather than a straight one [9].

Strip Model

The strip model, also known as the bond model [9], describes a load path for shear transfer of a slab-column connection and is the result of a modification of the truss model proposed by Alexander and Simmonds [2]. Because the strip model provides a lower bound estimate, it does not model a particular failure mechanism, yet it provides a load path that is consistent with the static constraints, making sure it does not exceed the material capacities.

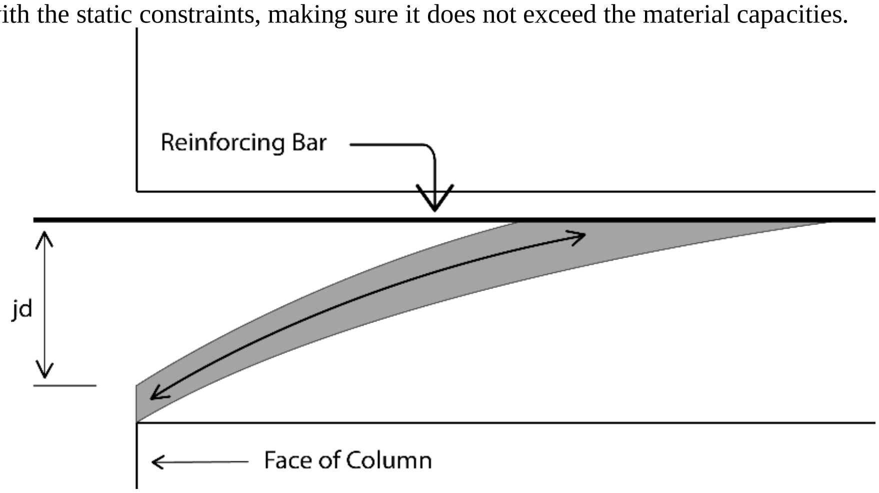

Figure 6: Arched compression strut, modified from [9]

The shear transfer between the slab and column is related with the vertical force component of the compression struts. The compression strut is assumed to be inclined with respect to the horizontal plane of the slab and the magnitude of the inclination depends on the conditions at the intersection of the strut and its attendant tension tie.

For the model to work properly, a rectangular layout of reinforcement must exist within the slab. The area of consideration is divided into radial strips and quadrants, as shown in Figure 7. The strips extend from the column parallel to the reinforcement to a line of zero shear either at the edge of the specimen or at the center of the span. The strips separate the columns from the quadrants so that no load can reach the column without passing through one of the radial strips. Each radial strip supports the adjacent quadrants and as a result, is loaded in shear on its side faces. The width of each strip is defined by the column width *c* and the length of the strip is defined as l_w.

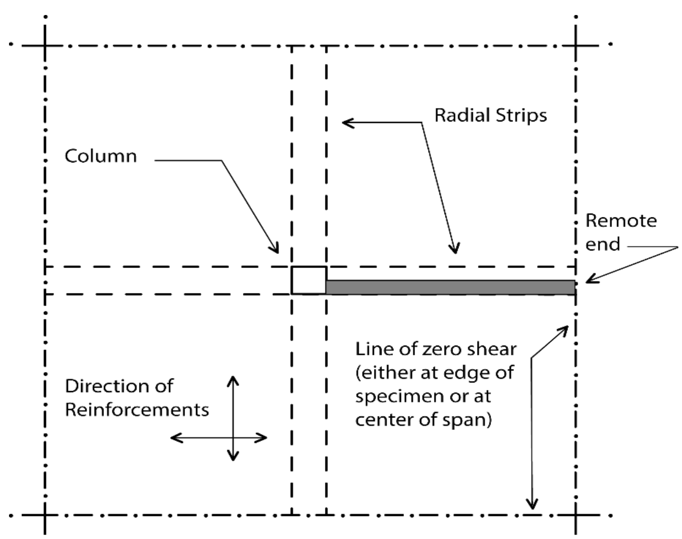

Figure 7: Layout of Radial Strips modified from [9]

In the quadrants, shear transfer is carried by beam action whereas the radial strips carry shear by means of arching action. The compression arch inside the radial strip varies from a maximum at the face of the column, where the slope of the arch is large to a minimum where the arch intersects the reinforcement and the slope is small. The horizontal component of the strut is assumed constant through the length of the strut and the shear that is carried by the arch at the face of the column must be dissipated in a direction perpendicular to the arch at some distance away from the column. The rate at which shear dissipates determines the curvature of the arch, and the mechanism of shear transfer across the side faces of the radial strip must be compatible with a constant moment arm *jd* perpendicular to the radial strip.

The capacity of the strip can be quantified by its flexural capacity and the ability of the slab to generate bar force gradient. The shear capacity of the connection is equal to the sum of all independent shear capacities of the radial strips. In order to find a lower bound solution three requirements are needed. The first one regards statics, where equilibrium must be satisfied at every point. The second one states that no element may be loaded beyond its relevant capacity and finally, there must be enough ductility at the connection in order to redistribute the load prior to failure.

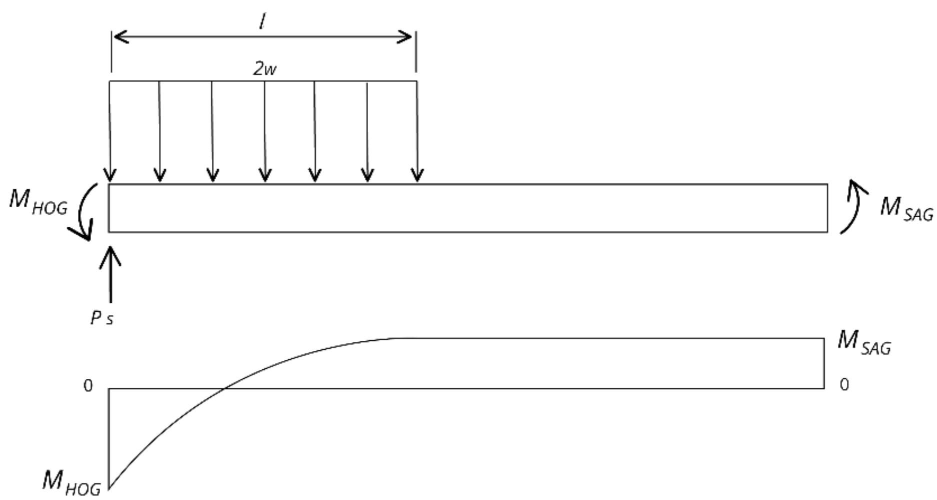

Figure 8: Equilibrium of a radial strip, modified from [9]

A simple model of a cantilever beam, as in Figure 8, with hogging (M_{HOG}) and sagging (M_{SAG}) moment capacities may be used to analyze a single radial strip. The total flexural capacity M_s can be taken as the sum of M_{HOG} and M_{SAG}. The total load transferred by the radial strip to the column is taken as P_s. Each strip supports the adjacent quadrants and, as a result is loaded in shear on each side with the one-way shear capacity, *w*. Since each strip of an interior slab-column connection has two side faces, the loading term becomes 2*w* as seen in Figure 8. Taking rotational and vertical equilibrium leads to the following expressions:

$$M_s = \frac{2wl^2}{2} \tag{7}$$

$$P_s = 2wl \tag{8}$$

Solving for the loaded length *l* from Eq. (7) and substituting into Eq. (8), and summing the capacity of the four strips yields the following equation for the total capacity:

$$P = \sum P_s = 4\left(2\sqrt{M_s w}\right) = 8\sqrt{M_s w} \tag{9}$$

METHODS:

Description of Database:

The database developed by Vargas [10] contains 66 experiments of eccentric punching shear on flat slabs, including slabs with shear reinforcement. For this analysis, only slabs without shear reinforcement were used. The experiments used for the analysis are tested by Albuquerque [11], Krüger [12], Hammil and Ghali [13], Narashimhan [14], Zaghlool [15], and Anis [16].

Typical slab-column geometries found in the database are corner connections, edge connections and interior connections with unbalanced moments. Table 1 presents the most relevant input parameters of the experiments in the database that were tested without shear reinforcement. h is the slab thickness, d is the effective depth, L_x and L_y the lengths of the specimen in the x-direction and y- direction respectively, a is the shear span, a_v is the clear shear span, and ρ is the longitudinal reinforcement ratio. The database of slabs without shear reinforcement shows that the majority of the experiments are made out of normal strength concrete. In order to ensure a punching shear failure most of the slabs were over-reinforced. Typical slab designs use reinforcement ratios of 0.6% - 0.8%; however, a ratio close to 1.25% was commonly used in the tested slabs [10]. Albuquerque slabs [11] were loaded incrementally to failure, and each experiment was held with a constant eccentricity. For the Kruger slabs [12], a special shape was given to the column so that it was possible to apply an axial force with a constant eccentricity. Hammil and Ghali slabs [13] were tested with four loading stages maintaining a constant eccentricity of 0.43 m (1.4 ft), approximately. Narashimhan slabs [14] were mounted vertically and consisted of a ten-stage loading procedure maintaining the eccentricity constant through each experiment. Zaghlool slabs [15] were also tested maintaining a constant eccentricity. For corner connections, the value of the eccentricity was measured as the ratio of the applied moment and the applied axial force. Results from the Annis slabs [16] show that during each experiment the eccentricity was held constant.

As output parameter, the load at failure was registered in the database. All the reported values for the sectional shear force at failure include the contribution of the self-weight when testing was performed in the gravitational direction. Most of the entries in the database failed in brittle punching shear and only a few slabs failed in flexure-induced punching shear [10].

Table 1: Important Parameters in Database

Parameter	Min	Max
h (mm)	102	180
d (mm)	76	153
L_x (mm)	1067	3000
L_y (mm)	965	3000
a (mm)	400	1375
a_v (mm)	200	1100
ρ (%)	0.72%	2.40%
f_{cm} (MPa)	26	59
a/d (-)	2.62	11.36
a_v/d (-)	1.31	9.09

Extended Strip Model

The Extended Strip Model is based on the Strip Model for concentric punching shear, and modifications to study maximum loads on reinforced concrete slab bridges [17]. The model describes the capacity of a slab-column connection with strips that work in arching action and slab quadrants that work in two-way flexure. Experiments have shown that the failure mode of slabs under concentrated loads is a combination of one-way and two-way shear as well as two-way flexure [17]. The Extended Strip Model considers the effects of geometry for describing the ultimate capacity of slabs under concentrated loads. This method is suitable for the design and assessment of elements that are in the transition zone between one-way and two-way shear.

The first modification is based on the observation that some slabs will have different dimensions, reinforcement ratios and effective depths in the longitudinal and transverse direction. The load on the y-direction strips will be determined by d_x since the cross-section of the intersection between the strip and the quadrant has the x-direction reinforcement as bending reinforcement. In the same sense, the load on the x-direction will be determined by d_y. As the depth of the specimen increases, the shear capacity does not increase proportionally. A recommendation for considering the size effect on the shear capacity results in the following expressions [17]:

$$w_{ACI,X}\left[\frac{kN}{m}\right]=0.167d_y\left[mm\right]\sqrt{f_c^{'}\left[MPa\right]}\left(\frac{100\,mm}{d\left[mm\right]}\right)^{\frac{1}{3}} \tag{10}$$

$$w_{ACI,X}\left[\frac{lbf}{in}\right]=2d_y\left[in\right]\sqrt{f_c^{'}\left[psi\right]}\left(\frac{3.94\,in}{d\left[in\right]}\right)^{\frac{1}{3}} \tag{11}$$

$$w_{ACI,Y}\left[\frac{kN}{m}\right]=0.167d_x\left[mm\right]\sqrt{f_c^{'}\left[MPa\right]}\left(\frac{100\,mm}{d\left[mm\right]}\right)^{\frac{1}{3}} \tag{12}$$

$$w_{ACI,Y}\left[\frac{lbf}{in}\right]=2d_X\left[in\right]\sqrt{f_c^{'}\left[psi\right]}\left(\frac{3.94\,in}{d\left[in\right]}\right)^{\frac{1}{3}} \tag{13}$$

Where d is the average effective depth between d_x and d_y. Lantsoght observed that the introduction of this size effect term leads to a good correspondence with experimental results [17].

As mentioned before, the capacity of the strip will be determined by the maximum stress that can occur at the interface between the strip and the quadrant for all considered loads. For specimens tested in the direction of gravity, the self-weight should be considered. This load also contributes to shear stresses in the slab. Therefore, in order to find the maximum value of the concentrated load, the effect of self-weight must be subtracted from the total available capacity. For laboratory experiments, this reduction will be small because the depths of the slabs that are commonly tested are relatively small [17]. The sectional shear at the position of the load can be transformed into a distributed load by dividing the sectional shear by the total width of the element. For strips in the *y*-direction, the total load then becomes:

$$q_{MAX,Y}=w_{ACI,Y}-v_{DL} \tag{14}$$

For loads that are close to the support, a direct strut can develop between the load and the support leading to an increase in the shear capacity because of a direct load transfer. To take this effect into account an enhancement factor is used as follows:

$$1\le\frac{2d_l}{a_v}\le 4 \tag{15}$$

In this expression, a_v is the face-to-face distance between the load and the support and d_l is the effective depth in the direction being considered.

In a case where continuity at the supports exists, the effect of both the hogging and sagging reinforcement needs to be considered when the load is placed closed to a continuous support. The quadrants between the load and the support will be subject to a change in moment from hogging over the support M_{SUP} to sagging at the position of the concentrated load in the span M_{SPAN}. The quadrants that are affected by the moment diagram are bordered by three strips: the *y*-direction strips and the *x*-direction strip between the load and the support. The moment capacity of these strips will be based on both the hogging and sagging reinforcement. This effect can be considered with the following factor:

$$\lambda_{moment}=\frac{M_{SUP}}{M_{SPAN}}\le 1 \tag{16}$$

The total moment capacity of these strips is taken as:

$$M_s=M_{SAG}+\lambda_{moment}M_{HOG} \tag{17}$$

In the case of edge columns, as seen in Figure 9 (a), only three strips can develop and only two quadrants are used. The free edge itself does not contribute to the capacity of the strips. So, for the *x*-direction strips, the critical shear can only be reached on one side of the strips. For the *y*-direction strip, both sides are supported with a quadrant and the shear capacity is analyzed on both sides. On the other hand, as seen in Figure 9 (b), when a column is placed close to the edge, four strips are developed. For these cases, the so called "edge-effect" can take place. If the length of the strip between the load and the free edge is smaller than the loaded length of the strip, the full capacity of the strip cannot develop because it can only carry load over the length of the strip. The value of the length to the free edge will then replace the loaded length of the strip for the determination of the capacity. The resulting expressions are shown for slab L1 from the Albuquerque [11] experiments with Eqs. (22) and (23).

Torsion is also an effect that needs to be considered for loads close to the support and for asymmetric loading conditions. This effect is considered by a reduction factor β on the applied distributed load on the strips. The derivation of the β factor comes from a number of finite element models of one-way slabs where the ratio of the torsional moments to the bending moments was studied [17]. The ratio is associated with the geometry of the position of the load and results in the following expression:

$$\beta = 0.8\frac{a}{d_x}\frac{b_r}{b} \text{ for } 0 \le \frac{a}{d_x} \le 2.5 \text{ and } 0 \le \frac{b_r}{b} \le 0.5 \tag{18}$$

$$\beta = 2\frac{b_r}{b} \text{ for } \frac{a}{d_x} > 2.5 \text{ and } 0 \le \frac{b_r}{b} \le 0.5 \tag{19}$$

Here, b_r is the distance from the center of the load to the free edge and a is the center-to-center distance between the load and the support. Figure 11 shows how β is applied to the distributed load in the quadrants between the load and the free edge

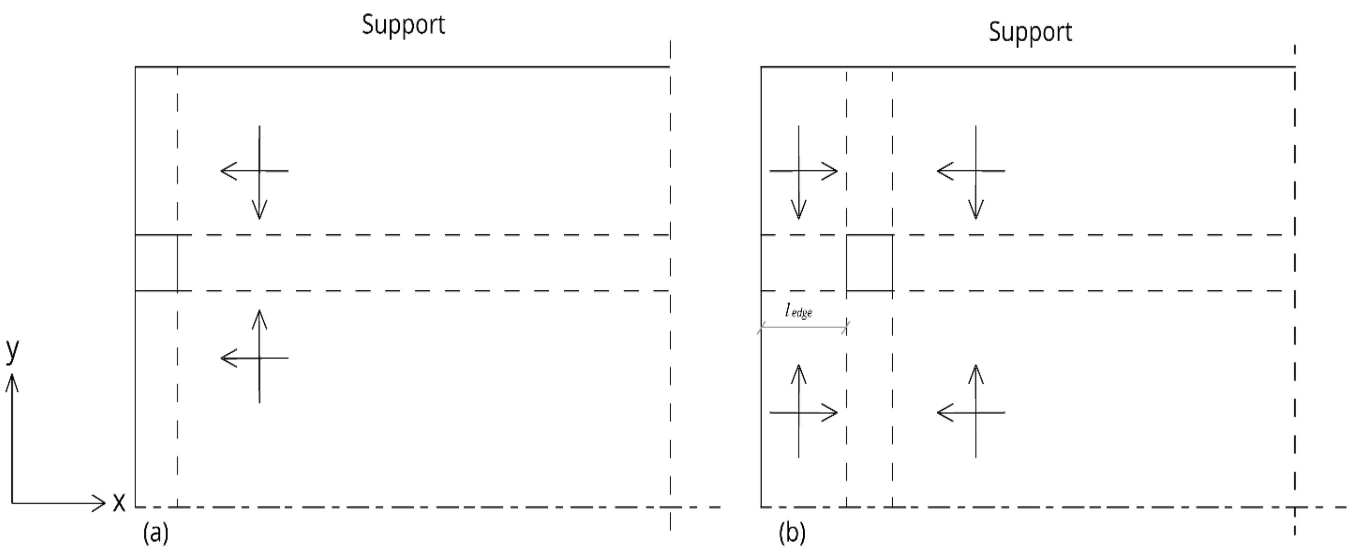

Figure 9 Columns acting close to supports, modified from [17]

For slab-column connections with unbalanced moments, the static equilibrium from Figure 8 needs to be adjusted. The external moments applied should be considered on the statical equilibrium of the strips. Figure 10 shows how the external moments applied affect directly the flexural capacity of the strips.

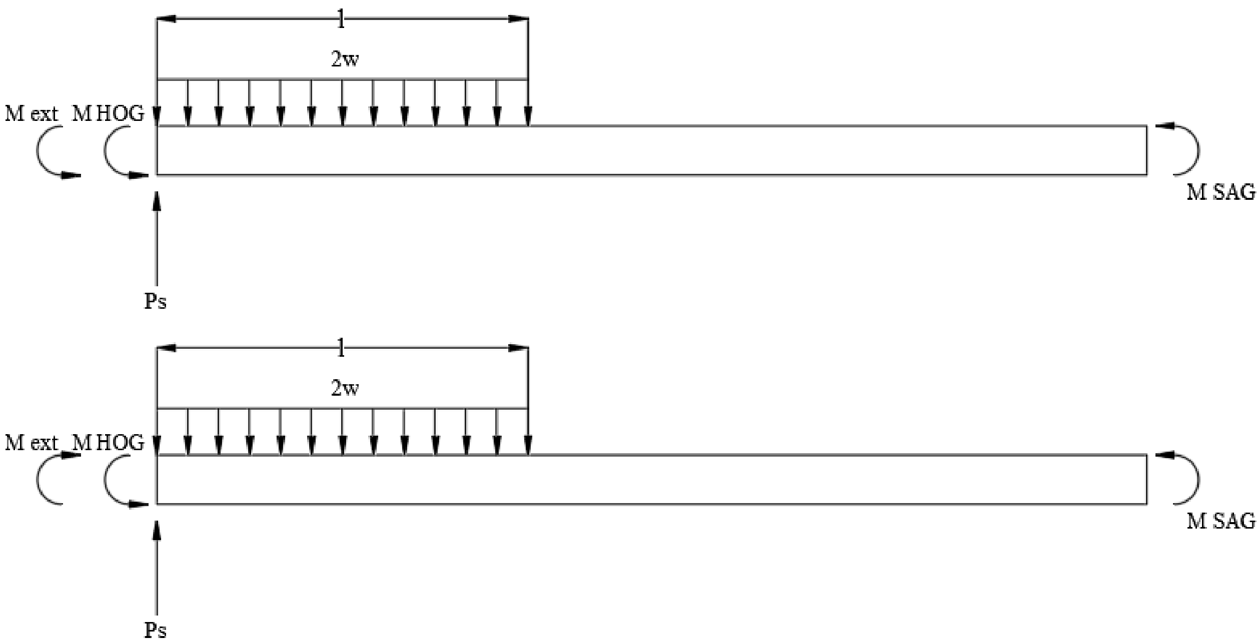

Figure 10: Application of the external moments on the static equilibrium of the strips

Figure 11 shows an example of one of the Albuquerque Slabs [11] with a complete overview of the loads applied in the *x*- and *y*-direction strips. The implications of static equilibrium, including the reduction of self-weight and the effects of torsion are included.

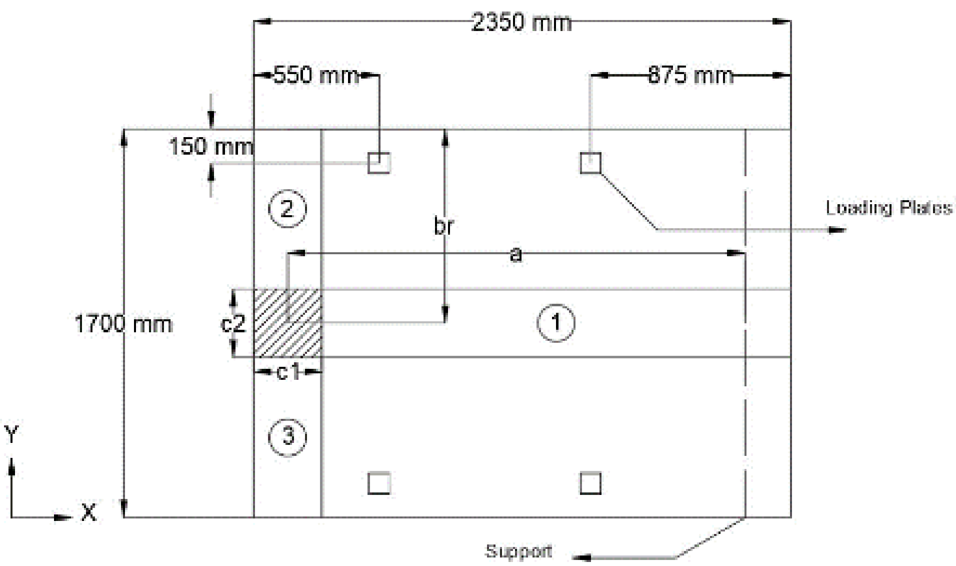

Figure 11: Overview of loads applied in *x*- and *y*-direction strips for experiment L1 from Albuquerque [11]

The resulting maximum load according to the Extended Strip Model is:

$$P = P_{s1} + P_{s2} + P_{s3} \tag{20}$$

$$P_{s1} = \frac{2d_x}{a_v}\sqrt{2(1+\beta)M_{s,x}w_{ACI,X}} \tag{21}$$

$$P_{s2} = P_{s3} = \begin{cases} \sqrt{2\beta M_{s,y}(w_{ACI,Y} - v_{DL})} & l_{edge} < l \\ \beta(w_{ACI,Y} - v_{DL})l_{edge} & l_{edge} > l \end{cases} \tag{22}$$

The loaded length of strips 2 and 3 is determined as:

$$l = \sqrt{\frac{2M_{sy}}{\beta(w_{ACI,Y} - v_{DL})}} \tag{23}$$

RESULTS

Comparison of Predictions with Database:

In this section, the maximum load predicted with the Extended Strip Model will be compared with the maximum concentrated load obtained in the experiments from the following references: Albuquerque [11], Krüger [12], Hamil and Ghali [13], Narashimhan [14], Zaghlool [15], and Anis [16]. Material properties, slab geometries and reinforcement layouts were taken from the database [10].

The results of the calculations are summarized in Table 2, where $\lambda_{moment,}$ and β are determined from Eqs. (16), (18) and (19) respectively. The values of P_{pred} are calculated from the statics of the strip depending on the geometry of the slab and the loading conditions. Table 2 shows the comparison between the tested to predicted values P_{Test}/P_{Pred}. The full calculations using the Extended Strip Model are available in the annex section of this paper. For all experiments, the external moments applied were considered on the flexural capacities of the strips as shown in Figure 10. References [13] and [15] present the application of external moments in both x and y directions.

For all the remaining references, the external moments were only analyzed in one direction according to the test setups. The capacity of each strip on the slabs analyzed were calculated according to the geometry and statical constraints presented in the slab. For interior connections, all strips were loaded in both directions. All interior slab-column connections were simply supported around the whole perimeter of the slab, therefore no β factor was calculated for those cases. For the interior connection of reference [14], the effect of self weight was neglected because the slab was hung vertically in the test frame. References [11], [13], [14], and [15] present edge and corner slab-column connections. For these cases, the loaded length of the strips was compared with the length of the edge strips. Eqs. (18), (19), and (20) were used to analyze the capacity of the strip.

A total of 22 slabs were analyzed with this situation. The values of M_{sup} and M_{span}, used to calculate λ_{moment} were taken from the linear finite element models developed by Vargas [10]. They represent the value of the moments at failure of the tested slabs.

The results show that the average of the tested to predicted values was 0.92 with a standard deviation of 0.31 and a coefficient of variation of 33.4%. The maximum and minimum ratio of tested to predicted values were 1.53 and 0.459 respectively.

Table 2: Overview of Test results and parameters

REFERENCE	SLAB	TYPE	M_{SUP} [kNm/m]	M_{SPAN} [kNm/m]	λ_{moment}	β	*Mext x* [kN m/m]	*Mext y* [kN m/m]	P_{pred} [kN]	P_{test} [kN]	P_{test}/P_{pred}
ALBUQUERQUE	L1	EDGE	40	54	0.74	1.00	-95	-	383	437	1.14
	L5	EDGE	92	111	0.83	1.00	38	-	427	654	1.53
	L6	EDGE	93	108	0.86	1.00	67	-	459	605	1.32
	L11	EDGE	105	115	0.91	1.00	112	-	450	615	1.37
	L12	EDGE	97	114	0.85	1.00	56	-	446	665	1.47
KRUGER	P16A	INT.	21	28	0.74	-	53	-	398	331	0.83
	P30A	INT.	17	25	0.70	-	86	-	411	270	0.66
HAMMIL & GHALI	NH1	COR.	42	113	0.37	1.00	43	43	158	147	0.93
	NH2	COR.	40	106	0.38	1.00	40	40	156	139	0.89
NARAYANI NARASHIMAN	L1	INT.	63	52	1.00	-	-122	-	540	399	0.74
	ES2	EDGE	83	63	1.00	1.00	78	-	329	342	1.04
	ES5	EDGE	83	63	1.00	1.00	112	-	337	492	1.46
ZAGHLOOL	Z-I (1)	COR.	24	57	0.43	1.00	19	19	153	74	0.49
	Z-II (1)	COR.	39	102	0.38	1.00	39	39	155	138	0.89
	Z-II (2)	COR.	48	136	0.36	1.00	53	53	160	177	1.11
	Z-II (3)	COR.	47	142	0.33	1.00	58	58	177	178	1.01
	Z-II (6)	COR.	16	80	0.20	1.00	39	39	152	82	0.54
	Z-II (8)	COR.	33	120	0.28	1.00	39	39	154	139	0.90
	Z-III(1)	COR.	43	125	0.34	1.00	132	132	159	180	1.13
	Z-IV(1)	EDGE	29	32	0.89	1.00	-	-48	243	122	0.50
	Z-V (1)	EDGE	44	53	0.84	1.00	-	-48	266	215	0.81
	Z-V (2)	EDGE	54	59	0.91	1.00	-	-94	273	547	0.90
	Z-V (3)	EDGE	57	65	0.87	1.00	-	-104	290	268	0.92
	Z-V (6)	EDGE	49	115	0.42	1.00	-	-88	255	117	0.46
	Z-VI (1)	EDGE	45	61	0.74	1.00	-	-107	221	265	1.20
ANIS	B.3	INT.	13	40	0.33	-	-18	-	204	191	0.94
	B.4	INT.	10	32	0.32	-	-26	-	195	140	0.72
	B.5	INT.	14	30	0.45	-	-39	-	187	125	0.67
	B.6	INT.	16	29	0.56	-	-54	-	176	116	0.66
	B.7	INT.	12	26	0.47	-	-66	-	144	70	0.48

Comparison of Predictions with Codes:
In this section, the predicted maximum load resulting from the Extended Strip Model is compared with the maximum concentrated load predicted with ACI-318-19 [4], Eurocode 2 [7], Critical Shear Crack Theory [18] and the *fib* Model Code 2010 [19]. All code predictions are taken from the work of Vargas [10]. Figure 12 shows the comparison of the results. Data points above the 45° line show a conservative result, whereas values below the line show un-conservative results

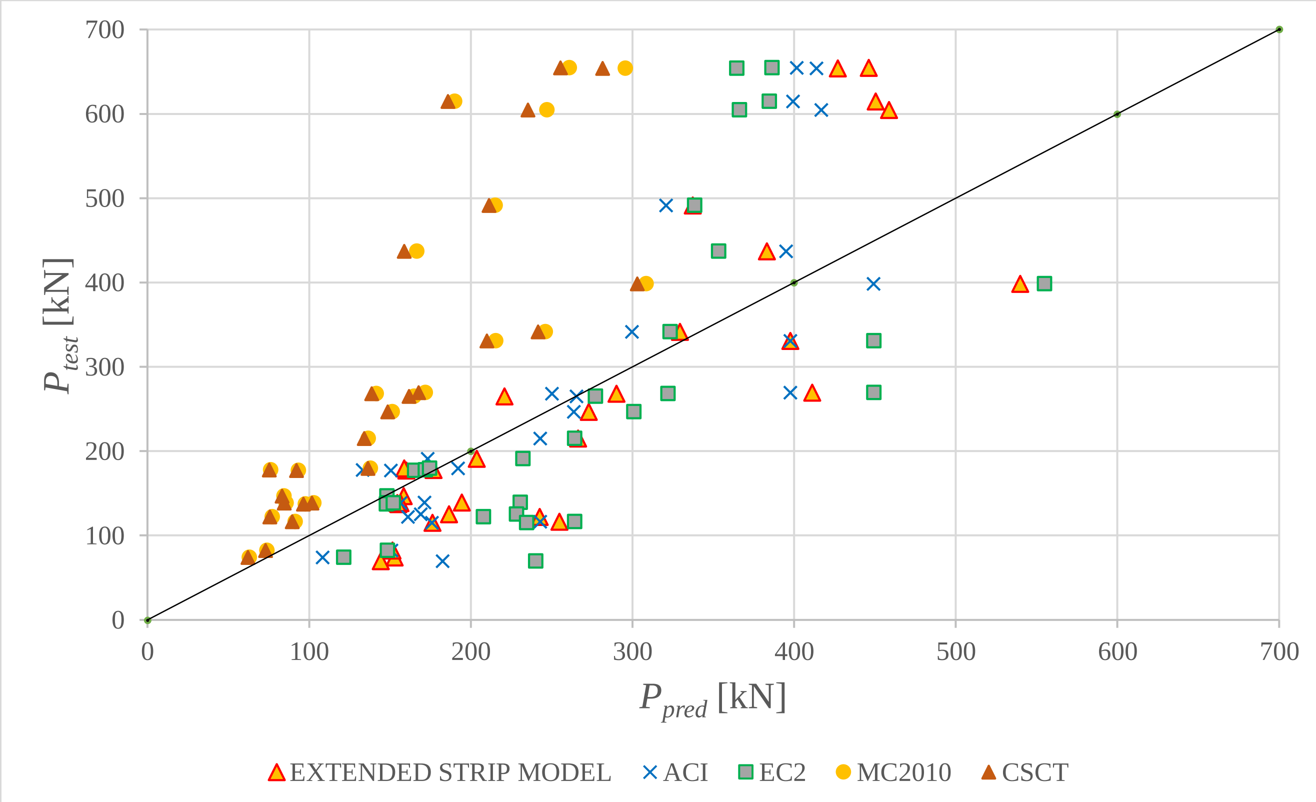

Figure 12: Prediction of Codes and Extended Strip Model

After analyzing the code expressions from ACI 318-19 [4], Eurocode 2 NEN-EN 1992-1-1:2005 [7], Model Code 2010 [19], and the Critical Shear Crack theory [18], the following statistical properties were calculated: average of P_{test}/P_{pred}, standard deviation (STD), coefficient of variation (COV) and the ranges of minimum and maximum values of P_{test}/P_{pred}. Table 3 shows the resulting statistical parameters for the 30 experiments considered in this study.

All code predictions present highly conservative results but show larger scatter than when using the Extended Strip Model, see Table 3. The NEN-EN 1992-1:2005 [7] code predictions show the least conservative results from all codes with an average tested to predicted capacity of 1.1 and it presents the highest scatter (COV = 36%). The coefficient of variation with the Extended Strip Model is 33%, which is the second lowest of all methods considered. The predictions with ACI 318-19 present the lowest coefficient of variation but also the highest standard deviation (STD = 0.45). Code provisions present empirical equations that include the effect of eccentricities. Reduction factors are added to the capacity of the slab-column connection and the stress on the punching perimeter is increased, but there is no a mechanics-based model that lies at the basis of these expressions. The Critical Shear Crack Theory is the only mechanics-based model, however, it was developed for concentric punching shear and uses simplified assumptions to include the effects of unbalanced moments.

Table 3: Statistical Properties of tested to predicted punching loads with codes and Extended Strip Model

MODEL	AVG	STD	COV	MIN	MAX
ACI	1.4	0.45	32 %	0.20	2.40
EC2	1.1	0.40	36 %	0.40	2.00
MC2010	1.3	0.43	33 %	0.50	2.30
CSCT	1.3	0.44	34 %	0.50	2.40
EXTENDED STRIP MODEL	0.9	0.30	33 %	0.46	1.53

DISCUSSION

The Extended Strip Model is derived from the strip model for concentric punching shear in slabs [17]. It is a lower-bound plasticity method that describes a load path prior to failure. The load path consists of strips, working in arching action, and quadrants working in two-way flexure. Failure is assumed to occur at the interface of the strip and the quadrant. This model applies the concepts of one-way slabs under concentrated loads to explain the complex behavior of two-way shear. The Extended Strip Model takes into consideration the effects of the geometry for describing the ultimate capacity of a slab-column connection and is suitable for the design and assessment of elements that are in the transition between one-way and two-way shear.

The analyzed experiments show several parameters that are varied, such as the concrete compressive strength, slab geometries, and the reinforcement layout. Slabs with higher concrete strength present higher one-way shear capacities. The one-way shear capacity is directly related to the maximum tensile strength of the concrete. The tensile strength of concrete is proportional to the compressive strength of concrete, therefore the shear strength between the strip and the quadrants increases as the concrete strength increases. The bending moment capacity of a single strip is determined with Whitney's Stress Block Diagram for hogging and sagging reinforcement. Higher concrete strengths represent a higher compressive stress distribution which, indeed, increases the flexural capacity.

Slabs with higher longitudinal reinforcement ratios present higher flexural capacities on the strips as a result of the internal equilibrium. For shear capacity, increasing the amount of longitudinal reinforcement increases the dowel action capacity. Most of the slabs considered were over-reinforced in order to ensure a punching failure. A ratio close to 1.25% was commonly used in the tested slabs [10]. A result of these high reinforcement ratio is that one of the basic assumptions of the Extended Strip Model, i.e. that the reinforcement steel is yielding at failure, may not be fulfilled. For such cases, it is necessary to estimate the stress in the steel to determine the capacity of the strips, which requires more computational time and effort.

Results of the experiments show that there is a significant reduction of the punching capacity of slab-column connections when subjected to shear and unbalanced moments. The effect of the external moments is considered in the static equilibrium of the strips. For all slab-column connections, sagging moments will reduce the capacity of the strip and hogging moments will increase the capacity of the strip. All the experiments were either interior, edge or corner slab-column connections. Interior slab-column connections show higher capacities than edge and corner slab-column connections because the effect of torsion is less than in corner and edge columns and more material of the surrounding slab can be activated. This is as expected, because most flat slab designs are governed by the ultimate capacity of corner and edge slab-column connections. References Hamil & Ghali [13] and Zaghlool [15] corner slabs (ZI, ZII and ZIII series) present external moments in both directions. For these cases the static equilibrium of the strips in both directions include the effect of the external moments. Some experiments show a significant reduction in the capacity when subjected to loads with relatively high eccentricities. For Zaghlool's [15] experiments, this can be seen in slabs ZII(6) and ZV(6) with a ratio of P_{Test}/P_{Pred} of 0.54 and 0.46 respectively as seen in Table 2. In addition, Anis [16] experiments show that slabs B.6 and B.7 present P_{Test}/P_{Pred} ratios of 0.66 and 0.48 respectively as seen in Table 2.All the slabs mentioned before were tested with relatively high eccentricities. For these cases, the effect of high eccentricities is directly related to a reduction in the capacity of the slab-column connection. Figure 13 shows a significant reduction in the ratio of P_{Test}/P_{Pred} for experiments with high eccentricities. This is due to the presence of higher torsional moments in the slabs as the eccentricities become higher and the interaction between shear and moment. The Extended Strip Model uses a factor β to consider the effects of torsion. To derive an expression for β, Valdivieso [20] performed several linear finite element models on different slabs with two supports subjected to a distributed load, representing a truck wheel print. The load was varied along the longitudinal and transverse direction and finally, the ratio of the torsional moments to the bending moments were studied. Valdivieso concluded that as the load approaches the center of the slab, the effect of torsion becomes less at the position of the load. Another conclusion stated that as the load was closer to the support, the torsional moments were larger, and the bending moments became smaller [20]. For these types of cases, the effect of shear becomes more important relative to bending. For future investigation, it would be interesting to include a new parameter that considers the effect of the eccentricity on the capacity of two-way flat slabs. β is based on models on one-way slabs so there are some inconsistencies when using it in two-way flexural systems. In addition, the interaction between moment and shear should be considered based on interaction diagrams for larger eccentricities [8].

The testing setup changed in each series of experiments and some tests such as those reported in Hamil & Ghali [13], Narashimhan [14], and Zaghlool [15] were tested vertically to reduce the effect of the self-weight. In these cases, the interface between the strip and the quadrant will only carry shear induced by the external load itself. The self-weight of the slab is in a direction perpendicular to the shear capacity between the quadrant and the strip, so this effect can be neglected on the slabs that were tested vertically. All the other slabs, which include the effect of self-weight, do not show a significant change in the capacity of the slab-column connection. This result was expected because the depths of the slabs are relatively low.

All the experiments analyzed consider only slabs without shear reinforcement. Analyzing slabs with shear reinforcement should include a modification in the extended strip model in order to include the effect of the shear reinforcement in the capacity of the strips. Additionally, it would be interesting to study the effect of high strength concrete on the capacity of slab-column connections.

Reference [17] shows an example of the application of the extended strip model on span 2 of the Ruytenschildt bridge. The tested to predicted capacity was 1.26 as expected for a lower-bound plasticity method [17]. On the other hand, results from the slabs in the database show an average ratio of P_{Test}/P_{Pred} of 0.92. This may seem like it does not agree with the concept of a lower-bound plasticity-based method because the majority of the capacities show a predicted value greater than a tested one. However, this might be because the factor β is based on experiments on one-way slabs. The effects of high eccentricities on the capacities of the slabs, as seen in Figure 13, show that a significant reduction in the tested experiments is due to loading conditions with high eccentricities. Even though Figure 12 shows that the performance of the Extended Strip Model is uniform, it can be concluded that the model gives a good but slightly unconservative estimate for the capacity of the tested slabs. We can also observe in Figure 13 that as the eccentricity increases, the proposed model is not sufficient to predict the maximum load, and a shear-moment interaction diagram [8] should be developed for the considered slab-column connection. Our proposed model can be used for eccentricities up to 300 mm.

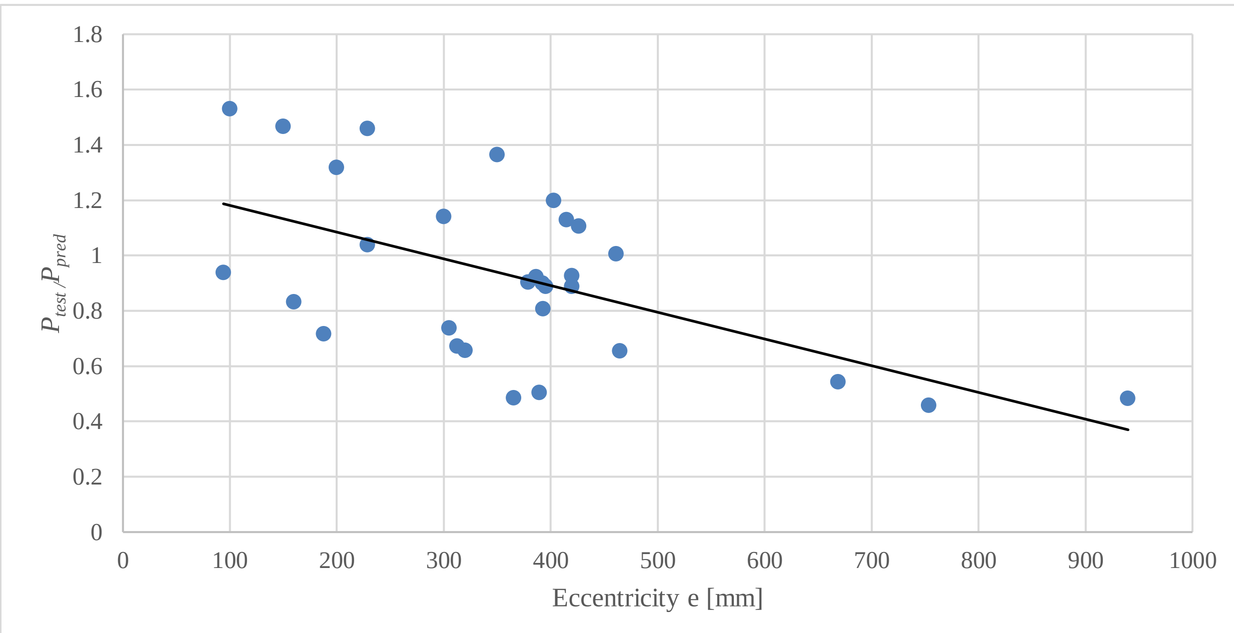

Figure 13: Effect of Eccentricity in the Capacity of Slab-Column Connections

SUMMARY AND CONCLUSIONS

Reinforced concrete flat slabs are suitable design solutions for the construction of mid- to high-rise buildings, yet special attention needs to be given when analyzing the punching capacity of a slab-column connection subjected to shear and unbalanced moments. Experiments have shown that the failure mechanism of a slab-column connection consists of a combination of one-way shear, two-way shear, flexure and torsion. The Extended Strip Model can be used to explain the behavior of two way flexural systems by combining one-way shear limits with localized arching behavior. In this work, we applied the Extended Strip Model to eccentric punching shear experiments. For this purpose, we adjusted the model to consider the effect of the externally applied bending moment on the static equilibrium of the strip. The maximum capacity of the slab-column connection is assumed to be related to the interface between the slabs and strips reaching a shear stress equal to the one-way shear capacity. The Extended Strip Model does not describe a failure mechanism yet it describes a load path that does not violate strength limits for flexure or one-way shear. It has been demonstrated that if sufficient ductility is given in the slab-column connection, the load predicted from the Extended Strip Model is a lower-bound solution for the capacity of the system.

The Extended Strip Model includes the following elements that influence the maximum load in the slab-column connection:

- The effect of different longitudinal and transverse longitudinal reinforcement.
- The model proposes the effect of the concentrated load by itself. Therefore, the effect of self-weight at the interface between the quadrant and the strip is subtracted from the capacity of the strips in the y-direction.
- For slabs with large thickness, a size effect factor is added to the one-way shear capacity considering that shear does not increase proportionally with size.
- For loads close to the support an enhancement factor is added to consider the formation of a direct compression strut between the load and the support
- The method also considers the effect of continuity at the support
- For loads that are close to the free edge, the so called "free-edge effect" can occur. A torsional factor is included in these cases and the actual length of the strip is compared to the loaded length to determine the capacity of the strip.

When using the Extended Strip Model, expressions that calculate limiting two-way shear stresses are not necessary and results show a relatively low coefficient of variation for a complex shear problem. Even though the extended strip model for two-way flexural systems is slightly unconservative, it presents a good estimate of the capacity of reinforced concrete slabs under concentrated loads subjected to shear and unbalanced moments. The model can be applied for eccentricities up to 300 mm, after which shear-moment interaction diagrams need to be developed to find the maximum load on the slab-column connection. Because of its versatility, it can be used for assessment of existing structures as well as the design of new ones.

LIST OF NOTATIONS:

a = shear span (center-to-center distance between load and support)
a_i = depth of Whitney's stress block for compression zone
a_v = clear shear span (face-to-face distance between load and support)
b = slab width
b_o = punching perimeter of a slab-column connection
b_r = distance from the center of the load to the free edge
b_1 = total width of the critical section measured perpendicular to the axis about which the moment acts
b_2 = total width of the critical section measured parallel to the axis about which the moment acts
c = distance from the centroid of the critical section to the point where the shear stress is calculated
c_1 = column width in the x-direction
c_2 = column width in the y-direction
d_x = effective depth in the x-direction
d_y = effective depth in the y-direction
d = average effective depth between d_x and d_y
f'_c = average compressive strength of concrete
f_{ct} = tensile strength of concrete
f_y = yield strength of longitudinal reinforcement
h = slab thickness
jd = internal lever arm between steel's centroid to Whitney's stress block diagram
k_c = column size effect factor
l = loaded length of shear stress between strip and quadrant
l_{edge} = length of strip close to edge
v_{ED} = design shear stress from EC2
v_c = punching resistance provided by the concrete for ACI 318-19
v_u = maximum shear stress for ACI 318-19
v_s = punching resistance provided by the steel for ACI 318-19
w = maximum shear at the interface between the strip and the quadrant
$w_{ACI\ X}$ = one-way shear expression with size effect from ACI for strips in the x-direction
$w_{ACI\ Y}$ = one-way shear expression with size effect from ACI for strips in the y-direction
A_{sx_bott} = area of bottom longitudinal tension reinforcement in the x-direction
A_{sx_top} = area of top longitudinal tension reinforcement in the x-direction

A_{sy_bott} = area of bottom longitudinal tension reinforcement in the y-direction
A_{sy_top} = area of top longitudinal tension reinforcement in the y-direction
Jc = polar moment of inertia of the critical section according to ACI 318-19
M_{ext} = external moment applied on the slab
M_u = factored moment applied on the slab
M_s = total flexural capacity of a single radial strip
M_{HOG} = hogging moment capacity
M_{SAG} = sagging moment capacity
M_{SPAN} = span moment generated from concentrated load P
M_{SUP} = support moment generated from concentrated load P
L = span length for a simply supported slab.
P = concentrated load
T = steel's tensile strength
V_{ED} = design shear strength from EC2
V_u = factored shear applied on the slab according to ACI 318-19
β_{EC} = enhancement factor for eccentric shear from EC2
β = reduction factor on the applied distributed load on the strips due to the effect of torsion
γ_f = fraction of the unbalanced moment transferred by flexure
γ_v = fraction of the unbalanced moment transferred by shear
λ_{moment} = factor considering the effect of both hogging and sagging reinforcement when the load is placed on a support

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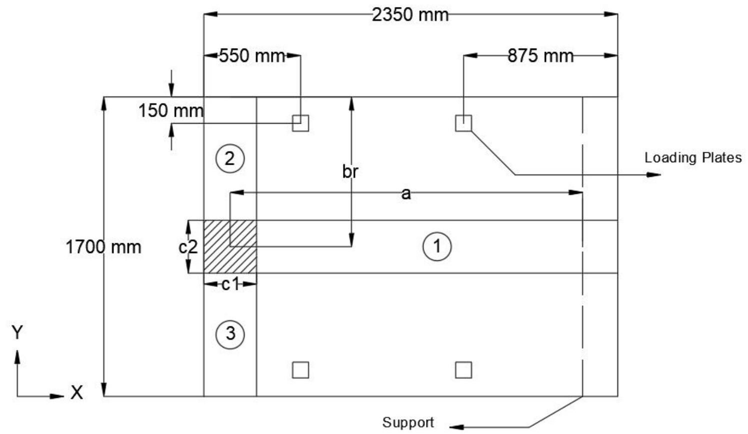
ANNEX 1: ALBUQUERQUE SLAB CALCULATIONS



SLAB L1

STRIP 1 CALCULATIONS

Data: $a_v := 2350\ mm - 200\ mm - 300\ mm$ $\quad b := 1700\ mm$ $\quad c1 := 300\ mm$

$b_r := \frac{1700}{2}\ mm$ $\quad a := 2350\ mm - 200\ mm - \frac{300}{2}\ mm$ $\quad c2 := 300\ mm$

$d_x := 180\ mm - 20\ mm - \frac{16}{2}\ mm$ $\quad d_y := 180\ mm - 20\ mm - 16\ mm - \frac{12.5}{2}\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 14.488\ cm$ $\quad d_x = 15.2\ cm$

Material Properties: $f'c := 46.8\ MPa$ $\quad$ for ϕ 16mm bars: $fy_1 := 558\ MPa$

for ϕ 12.5mm bars: $fy_2 := 530\ MPa$

Calculations: $a_v = 185\ cm$ $\quad E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\; \| \; \frac{2\ d_x}{a_v} \;\; \text{else} \;\; \| \; 1$ $\quad E.F = 1$

$d_x = 15.2\ cm$

Calculation of Enhancement Factor (E.F) due to loads close to supports

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \left\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \left\| 2 \cdot \frac{b_r}{b} \right. \end{array} \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 138.248\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 15 \cdot \left(201.1\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 24.89\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy_1 \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 41.453\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 15 \cdot \left(122.7\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 14.424\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy_2 \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 24.924\ kN \cdot m$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{Sup1} := 39.85\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 54.11\ \frac{kN \cdot m}{m} \qquad M_{ext} := -95\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.736$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \left\| \begin{array}{l} \left\| 1 \right. \\ \text{else} \\ \left\| \lambda_{moment} \right. \end{array} \right.$$

$\lambda_{moment} = 0.736$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 43.044\ kN \cdot m$$

$$P_{s1} := E.F \cdot \sqrt{2 \cdot (1+\beta) \cdot M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 154.282\ kN$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot (122.7\ mm^2) \qquad b := 2150\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 9.124\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy_2 \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.503\ kN \cdot m$$

$$A_{sy\_top} := 20 \cdot (201.1\ mm^2)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 26.241\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy_1 \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 39.028\ kN \cdot m$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 43.246\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 152.549\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 1.38\ \frac{kN}{m} \qquad L := 2000\ mm$$

$$b_r := \frac{1700}{2}\ mm = 850\ mm$$

$$\beta = 1$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot (w_{ACI\_y} - v_{DL})}} = 756.405\ mm$$

$$l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s2} := \text{if } l > l_s \quad \| \beta \cdot (w_{ACI\_y} - v_{DL}) \cdot l_s \quad \text{else} \quad \| \sqrt{2\ M_{sy} \cdot \beta \cdot (w_{ACI\_y} - v_{DL})}$$

$P_{s2} = 114.345\ kN$

$P_{s3} := P_{s2}$

$P := P_{s1} + P_{s2} + P_{s3}$ $\quad P = 382.972\ kN$

SLAB L5

STRIP 1 CALCULATIONS

Material Properties: $f'c := 44.7\ MPa$

Calculations:

$a_v = 185\ cm$

$a = 2000\ mm$

$b_r := \frac{1700}{2}\ mm$

$b := 1700\ mm$

$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\; \| \; \frac{2\ d_x}{a_v} \;\; \text{else} \;\; \| \; 1$

$E.F = 1$

Calculation of Enhancement Factor (E.F) due to loads close to supports

$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2}$
$\quad \| \; \text{if } 0 \le \frac{a}{d_x} \le 2.5$
$\quad\quad \| \; 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b}$
$\quad \| \; \text{else if } \frac{a}{d_x} > 2.5$
$\quad\quad \| \; 2 \cdot \frac{b_r}{b}$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 135.11\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 15 \cdot \left(201.1\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 26.059\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy_1 \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 41.279\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 15 \cdot \left(122.7\ mm^2\right)$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 15.102\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy_2 \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 24.866\ kN \cdot m$$

$$M_{Sup1} := 92.26\ \frac{kN \cdot m}{m} \quad M_{Span1} := 111.56\ \frac{kN \cdot m}{m} \quad M_{ext} := 38\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.827 \qquad \lambda_{moment} := \begin{cases} 1 & \text{if } \lambda_{moment} > 1 \\ \lambda_{moment} & \text{else} \end{cases} \qquad \lambda_{moment} = 0.827$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 68.549\ kN \cdot m$$

$$P_{s1} := E.F \cdot \sqrt{2 \cdot (1+\beta) \cdot M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 192.475\ kN$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(122.7\ mm^2\right) \qquad b := 2150\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 9.553\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy_2 \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.479\ kN \cdot m$$

$$A_{sy\_top} := 20 \cdot \left(201.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 27.473\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy_1 \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.835\ kN \cdot m$$

$$\lambda_{moment} = 0.827$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 46.596\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 149.087\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$v_{DL} := 1.38 \frac{kN}{m}$ $L := 2000\ mm$

$b_r := \frac{1700}{2}\ mm$

$\beta = 1$

Check for Loaded Length:

$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot (w_{ACI\_y} - v_{DL})}} = 794.308\ mm$

$l_s := \frac{1700}{2}\ mm = 850\ mm$

$P_{s2} :=$ if $l > l_s$
$\quad \beta \cdot (w_{ACI\_y} - v_{DL}) \cdot l_s$
else
$\quad \sqrt{2\ M_{sy} \cdot \beta \cdot (w_{ACI\_y} - v_{DL})}$

$P_{s2} = 117.325\ kN$

$P_{s3} := P_{s2}$

$P := P_{s1} + P_{s2} + P_{s3}$ $P = 427.126\ kN$

SLAB L6

STRIP 1 CALCULATIONS

Material Properties: $f'c := 52.1\ MPa$

Calculations:

$a_v = 185\ cm$

$a = 2000\ mm$

$b_r := \frac{1700}{2}\ mm$

$b := 1700\ mm$

$$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\; \left\| \frac{2\ d_x}{a_v} \right. \;\; \text{else} \;\; \left\| 1 \right.$$

$E.F = 1$

Calculation of Enhancement Factor (E.F) due to loads close to supports

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \left\| \text{if } 0 \le \frac{a}{d_x} \le 2.5 \;\; \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \;\; \text{else if } \frac{a}{d_x} > 2.5 \;\; \left\| 2 \cdot \frac{b_r}{b} \right. \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 145.866\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 15 \cdot \left(201.1\ mm^2 \right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 22.358\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy_1 \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 41.829\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 15 \cdot \left(122.7\ mm^2\right)$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 12.957\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy_2 \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 25.05\ kN \cdot m$$

$$M_{Sup1} := 92.96\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 107.73\ \frac{kN \cdot m}{m} \qquad M_{ext} := 67\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.863$$

$$\lambda_{moment} := \begin{cases} 1 & \text{if } \lambda_{moment} > 1 \\ \lambda_{moment} & \text{else} \end{cases} \qquad \lambda_{moment} = 0.863$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 75.268\ kN \cdot m$$

$$P_{s1} := E.F \cdot \sqrt{2 \cdot (1 + \beta) \cdot M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 209.562\ kN$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(122.7\ mm^2\right) \qquad b := 2150\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 8.196\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy_2 \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.553\ kN \cdot m$$

$$A_{sy\_top} := 20 \cdot \left(201.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 23.571\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy_1 \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 39.446\ kN \cdot m$$

$$\lambda_{moment} = 0.863$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 48.591\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 160.956\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 1.38 \ \frac{kN}{m} \qquad L := 2000 \ mm$$

$$b_r := \frac{1700}{2} \ mm$$

$$\beta = 1$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot \left(w_{ACI\_y} - v_{DL}\right)}} = 780.39 \ mm$$

$$l_s := \frac{1700}{2} \ mm = 850 \ mm$$

$$P_{s2} := \text{if } l > l_s \ \Big\| \ \beta \cdot \left(w_{ACI\_y} - v_{DL}\right) \cdot l_s \ \text{ else } \Big\| \ \sqrt{2 \ M_{sy} \cdot \beta \cdot \left(w_{ACI\_y} - v_{DL}\right)}$$

$$P_{s2} = 124.531 \ kN$$

$$P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 458.625 \ kN$$

SLAB L11

STRIP 1 CALCULATIONS

Material Properties: $f'c := 43.1\ MPa$

Calculations: $a_v = 185\ cm$

$a = (2 \cdot 10^3)\ mm$

$b_r := \frac{1700}{2}\ mm$

$b := 1700\ mm$

$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\; \| \; \frac{2\ d_x}{a_v} \;\; \text{else} \;\; \| \; 1$

$E.F = 1$

Calculation of Enhancement Factor (E.F) due to loads close to supports

$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2}$
$\quad \text{if } 0 \le \frac{a}{d_x} \le 2.5$
$\quad\quad 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b}$
$\quad \text{else if } \frac{a}{d_x} > 2.5$
$\quad\quad 2 \cdot \frac{b_r}{b}$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 132.67\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 15 \cdot (201.1\ mm^2)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 27.027\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy_1 \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 41.136\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 15 \cdot \left(122.7\ mm^2\right)$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 15.663\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy_2 \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 24.817\ kN \cdot m$$

$$M_{Sup1} := 104.87\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 115.37\ \frac{kN \cdot m}{m} \qquad M_{ext} := 112\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.909 \qquad \lambda_{moment} := \begin{cases} 1 & \text{if } \lambda_{moment} > 1 \\ \lambda_{moment} & \text{else} \end{cases} \qquad \lambda_{moment} = 0.909$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 83.459\ kN \cdot m$$

$$P_{s1} := E.F \cdot \sqrt{2 \cdot (1 + \beta) \cdot M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 210.452\ kN$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(122.7\ mm^2\right) \qquad b := 2150\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 9.908\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy_2 \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.46\ kN \cdot m$$

$$A_{sy\_top} := 20 \cdot \left(201.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 28.493\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy_1 \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.676\ kN \cdot m$$

$$\lambda_{moment} = 0.909$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 49.616\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 146.395\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 1.38\ \frac{kN}{m} \quad L := 2000\ mm$$

$$b_r := \frac{1700}{2}\ mm = 850\ mm$$

$$\beta = 1$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot \left(w_{ACI\_y} - v_{DL}\right)}} = 827.216\ mm$$

$$l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s2} := \text{if } l > l_s \;\; \left\| \beta \cdot \left(w_{ACI\_y} - v_{DL}\right) \cdot l_s \right. \;\; \text{else} \;\; \left\| \sqrt{2\ M_{sy} \cdot \beta \cdot \left(w_{ACI\_y} - v_{DL}\right)} \right.$$

$$P_{s2} = 119.959\ kN$$

$$P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 450.369\ kN$$

SLAB L12

STRIP 1 CALCULATIONS

Material Properties: $f'c := 44.1\ MPa$

Calculations:

$a_v = 185\ cm$

$a = (2 \cdot 10^3)\ mm$

$b_r := \frac{1700}{2}\ mm$

$b := 1700\ mm$

$$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\; \left\| \frac{2\ d_x}{a_v} \right. \;\; \text{else} \;\; \| 1$$

$E.F = 1$

Calculation of Enhancement Factor (E.F) due to loads close to supports

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \left\| \text{if } 0 \le \frac{a}{d_x} \le 2.5 \;\; \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \;\; \text{else if } \frac{a}{d_x} > 2.5 \;\; \left\| 2 \cdot \frac{b_r}{b} \right. \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 134.201\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 15 \cdot (201.1\ mm^2)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 26.414\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy_1 \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 41.227\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 15 \cdot \left(122.7\ mm^2\right)$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 15.308\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy_2 \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 24.848\ kN \cdot m$$

$$M_{Sup1} := 96.60\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 114.26\ \frac{kN \cdot m}{m} \qquad M_{ext} := 56\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.845 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \ \| \ 1 \ \text{else} \ \| \ \lambda_{moment} \qquad \lambda_{moment} = 0.845$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 72.116\ kN \cdot m$$

$$P_{s1} := E.F \cdot \sqrt{2 \cdot (1 + \beta) \cdot M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 196.754\ kN$$

STRIP 2 CALCULATIONS

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(122.7\ mm^2\right) \qquad b := 2150\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy_2}{0.85 \cdot f'c \cdot b} = 9.683\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy_2 \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.472\ kN \cdot m$$

$$A_{sy\_top} := 20 \cdot \left(201.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy_1}{0.85 \cdot f'c \cdot b} = 27.847\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy_1 \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.777\ kN \cdot m$$

$$\lambda_{moment} = 0.845$$

$$M_{sy} := M_{sagy} + M_{hogy} = 53.249\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 148.083\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 1.38 \ \frac{kN}{m} \qquad L := 2000 \ mm$$

$$b_r := \frac{1700}{2} \ mm = 85 \ cm$$

$$\beta = 1$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot \left(w_{ACI\_y} - v_{DL}\right)}} = 852.023 \ mm$$

$$l_s := \frac{1700}{2} \ mm = 850 \ mm$$

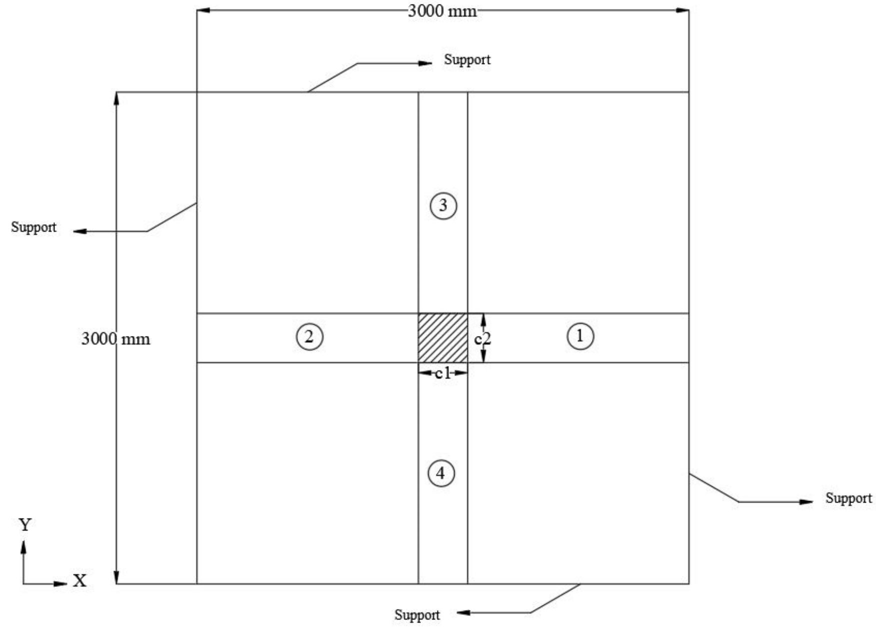
$$P_{s2} := \text{if } l > l_s \;\; \| \; \beta \cdot \left(w_{ACI\_y} - v_{DL}\right) \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2 \ M_{sy} \cdot \beta \cdot \left(w_{ACI\_y} - v_{DL}\right)}$$

$$P_{s2} = 124.698 \ kN$$

$$P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 446.15 \ kN$$

ANNEX 2: KRUGER SLAB CALCULATIONS



SLAB P16A

<u>STRIP 1 CALCULATIONS</u>

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{3000}{2}\ mm - \frac{300}{2}\ mm$ $\quad b := 3000\ mm$ $\quad c1 := 300\ mm$

$b_r := \frac{3000}{2}\ mm = 1500\ mm$ $\quad a := \frac{3000}{2}\ mm$ $\quad c2 := 300\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$

Material Properties: $f'c := 35\ MPa$ $\quad fy := 480\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 111.515\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 24 \cdot \left(153.9\ mm^2\right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.865\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 19.691\ kN \cdot m$$

$$A_{sx\_top} := 0\ mm^2$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 0\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 0\ kN \cdot m$$

$$M_{Sup1} := 20.70\ \frac{kN \cdot m}{m} \quad M_{Span1} := 28.13\ \frac{kN \cdot m}{m} \quad M_{ext} := 53\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.736$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.736$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 24.991\ kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 105.583\ kN \qquad P_{s2} := P_{s1}$$

<u>STRIP 3 CALCULATIONS</u>

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$$a_v := \frac{3000}{2}\ mm - \frac{300}{2}\ mm \qquad b := 3000\ mm \qquad c1 := 300\ mm$$

$$a := \frac{3000}{2}\ mm \qquad c2 := 300\ mm$$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.865\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 19.691\ kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 0 \ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 0 \ kN \cdot m$$

$$\lambda_{moment} = 0.736$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 19.691 \ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 111.515 \ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 1.11 \ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 93.253 \ kN \qquad P_{s4} := P_{s3}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 397.671 \ kN$$

SLAB P30A

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{3000}{2}\ mm + \frac{300}{2}\ mm$ $\quad b := 3000\ mm$ $\quad c1 := 300\ mm$

$a := \frac{3000}{2}\ mm$ $\quad c2 := 300\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$

Material Properties: $f'c := 35\ MPa$ $\quad fy := 480\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$w_{ACI\_x} = 111.515\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 24 \cdot \left(153.9\ mm^2\right)$

$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.865\ mm$

$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 19.691\ kN \cdot m$

Bending moment capacity determined with Whitney's stress block diagram

$A_{sx\_top} := 0\ mm^2$

$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 0\ mm$

$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 0\ kN \cdot m$

Support Moment and Span moment where taken from SCIA model of the slab

$M_{Sup1} := 17.43\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 24.75\ \frac{kN \cdot m}{m}$ $\quad M_{ext} := 86\ kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.704$

$\lambda_{moment} :=$ if $\lambda_{moment} > 1$
  $\| 1$
else
  $\| \lambda_{moment}$

$\lambda_{moment} = 0.704$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 28.291\ kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 112.337\ kN \qquad P_{s2} := P_{s1}$$

<u>STRIP 3 CALCULATIONS</u>

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data: $a_v := \frac{3000}{2}\ mm - \frac{300}{2}\ mm \qquad b := 3000\ mm \qquad c1 := 300\ mm$

$a := \frac{3000}{2}\ mm \qquad c2 := 300\ mm$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.865\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 19.691\ kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 0\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 0\ kN \cdot m$$

$$\lambda_{moment} = 0.704$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 19.691\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 111.515\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

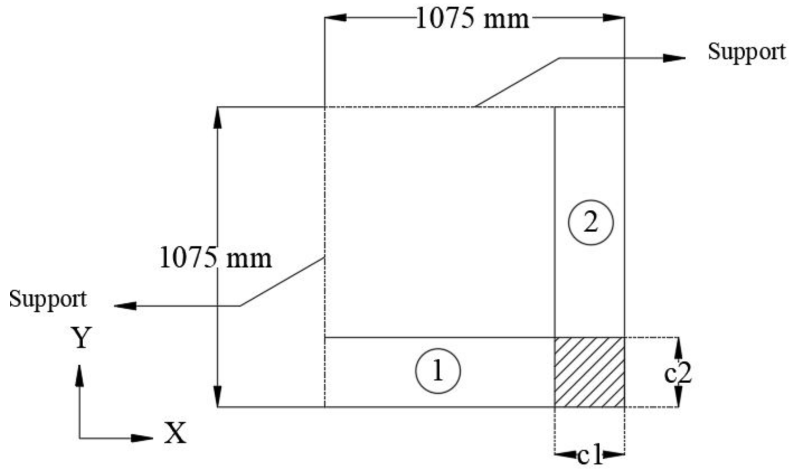
Dead Load Effect:

$$v_{DL} := 1.11\ \frac{kN}{m}$$

$P_{s3} := 2 \cdot \sqrt{M_{sy} \left(w_{ACI\_y} - v_{DL}\right)}$ $P_{s3} = 93.253$ ***kN*** $P_{s4} := P_{s3}$

$P := P_{s1} + P_{s2} + P_{s3} + P_{s4}$ $P = 411.181$ ***kN***

ANNEX 3: HAMMILL & GHALI SLAB CALCULATIONS



SLAB NH1

STRIP 1 CALCULATIONS

Data: $a_v := 1075\ mm - 250\ mm$ $b := 1075\ mm$

$a := 1075\ mm - \frac{250}{2}\ mm$ $c1 := 250\ mm$

$d_x := 114\ mm$ $d_y := 114\ mm$ $c2 := 250\ mm$

$d := \frac{d_x + d_y}{2}$ $d = 11.4\ cm$

Material Properties: $f'c := 46.8\ MPa$ $fy := 440\ MPa$

Calculations: $b_r := 1075\ mm - \frac{250}{2}\ mm = 950\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.767$ Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 123.927\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_bott} := 7 \cdot \left(113.1\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 8.146\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 8.905\ kN \cdot m$$

Support Moment and Span moment where taken from SCIA model of the slab

$$A_{sx\_top} := 9 \cdot \left(176.7\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.363\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 17.22\ kN \cdot m$$

$$M_{Sup1} := 41.87\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 112.56\ \frac{kN \cdot m}{m} \qquad M_{ext} := 43\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.372$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.372$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 25.311\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 639.121\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 79.205\ kN$$

STRIP 2 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 7 \cdot \left(113.1\ mm^2\right)$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 8.146\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 8.905\ kN \cdot m$$

$$A_{sy\_top} := 9 \cdot \left(176.7\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.363\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 17.22\ kN \cdot m$$

$$M_{ext} = 10\ kN \cdot m$$

$$\lambda_{moment} = 0.372 \qquad M_{ext} := 43\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 25.311\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 123.927\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect: Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 639.121\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s2} := \begin{cases} \beta \cdot w_{ACI\_y} \cdot l_s & \text{if } l > l_s \\ \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_y}} & \text{else} \end{cases}$$

$$P_{s2} = 79.205\ kN$$

$$P := P_{s1} + P_{s2} \qquad P = 158.409\ kN$$

SLAB NH2

STRIP 1 CALCULATIONS

Data: $a_v := 1075\ mm - 250\ mm$ $\quad b := 1075\ mm$

$a := 1075\ mm - \frac{250}{2}\ mm$ $\quad c1 := 250\ mm$

$d_x := 114\ mm$ $\quad d_y := 114\ mm$ $\quad c2 := 250\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 11.4\ cm$

Material Properties: $f'c := 46.8\ MPa$ $\quad fy := 440\ MPa$

Calculations: $b_r := 1075\ mm - \frac{250}{2}\ mm = 950\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.767$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 123.927\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 7 \cdot (113.1\ mm^2)$

$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 8.146\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 8.905\ kN \cdot m$$

$A_{sx\_top} := 9 \cdot (176.7\ mm^2)$

$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.363\ mm$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 17.22\ kN \cdot m$$

$M_{Sup1} := 39.86\ \dfrac{kN \cdot m}{m}$ $\quad M_{Span1} := 106.01\ \dfrac{kN \cdot m}{m}$ $\quad M_{ext} := 40\ kN \cdot m \cdot \dfrac{c2}{b}$

$\lambda_{moment} := \dfrac{M_{Sup1}}{M_{Span1}} = 0.376$

$$\lambda_{moment} := \begin{cases} 1 & \text{if } \lambda_{moment} > 1 \\ \lambda_{moment} & \text{else} \end{cases}$$

$\lambda_{moment} = 0.376$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 24.682\ kN \cdot m$

Check for Loaded Length:

$l := \sqrt{\dfrac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 631.137\ mm$

$l_s := 1075\ mm = 1075\ mm$

$$P_{s1} := \begin{cases} \beta \cdot w_{ACI\_x} \cdot l_s & \text{if } l > l_s \\ \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}} & \text{else} \end{cases}$$

$P_{s1} = 78.215\ kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 7 \cdot \left(113.1\ mm^2\right)$

$a_3 := \dfrac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 8.146\ mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \dfrac{a_3}{2}\right) \cdot \left(\dfrac{c1}{b}\right) = 8.905\ kN \cdot m$

$A_{sy\_top} := 9 \cdot \left(176.7\ mm^2\right)$

$a_4 := \dfrac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.363\ mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \dfrac{a_4}{2}\right) \cdot \left(\dfrac{c1}{b}\right) = 17.22\ kN \cdot m$

$\lambda_{moment} = 0.376$ $\quad M_{ext} := 40\ kN \cdot m \cdot \dfrac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 24.682\ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 123.927\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 631.137\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

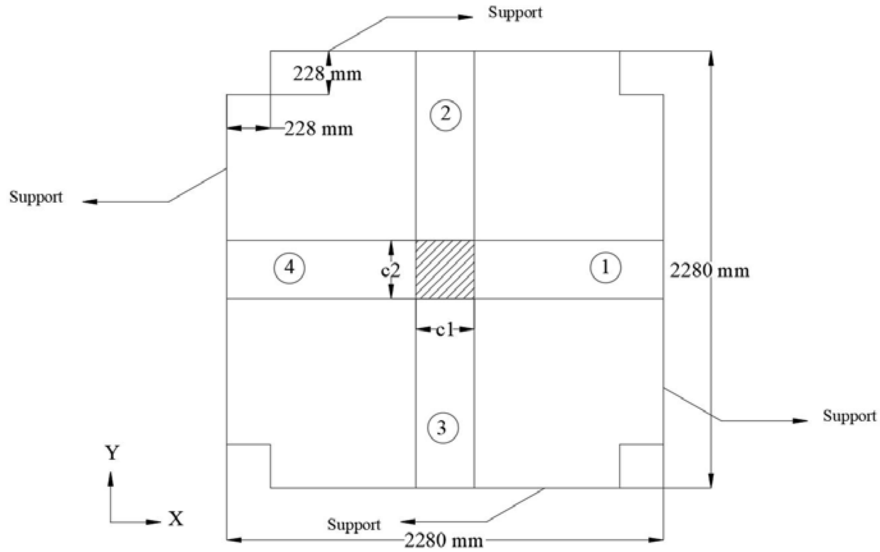
$$P_{s2} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s2} = 78.215\ kN$$

$$P := P_{s1} + P_{s2}$$

$$P = 156.431\ kN$$

ANNEX 4: NARAYANI NARASHIMAN SLAB CALCULATIONS



SLAB L1

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 4 will carry the same capacity

Data: $a_v := \frac{2280}{2}\ mm - 305\ mm$ $\qquad b := 2280\ mm$

$b_r := 0\ mm$ $\qquad a := \frac{2280}{2}\ mm - \frac{305}{2}\ mm$

$d_x := 135\ mm$ $\qquad d_y := 135\ mm$ $\qquad c1 := 305\ mm$

$d := \frac{d_x + d_y}{2}$ $\qquad d = 13.5\ cm$ $\qquad c2 := 305\ mm$

Material Properties: $f'c := 33\ MPa$ $\qquad fy := 398\ MPa$

One - Way Shear: $w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$

$w_{ACI\_x} = 116.481\ \frac{kN}{m}$ $\qquad$ Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

$a_v = 83.5\ cm$ $\qquad E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\|\; \frac{2\ d_x}{a_v} \text{ else } \|\; 1$ $\qquad E.F = 1$ $\qquad$ Calculation of Enhancement Factor (E.F) due to loads close to supports

$d_x = 13.5\ cm$

Flexural Capacity:

$$A_{sx\_bott} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 22.522\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 23.843\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 22.522\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 23.843\ kN \cdot m$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{Sup1} := 63.21\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 52.19\ \frac{kN \cdot m}{m} \qquad M_{ext} := -122\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 1.211$$

$\lambda_{moment} :=$ if $\lambda_{moment} > 1$
‖ 1
else
‖ λ_{moment}

$$\lambda_{moment} = 1$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 31.365\ kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 120.887\ kN \qquad P_{s4} := P_{s1}$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 22.522\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 23.843\ kN \cdot m$$

$$A_{sy\_top} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 22.522\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 23.843\ kN \cdot m$$

$$\lambda_{moment} = 1$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 47.685\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 116.481\ \frac{kN}{m}$$

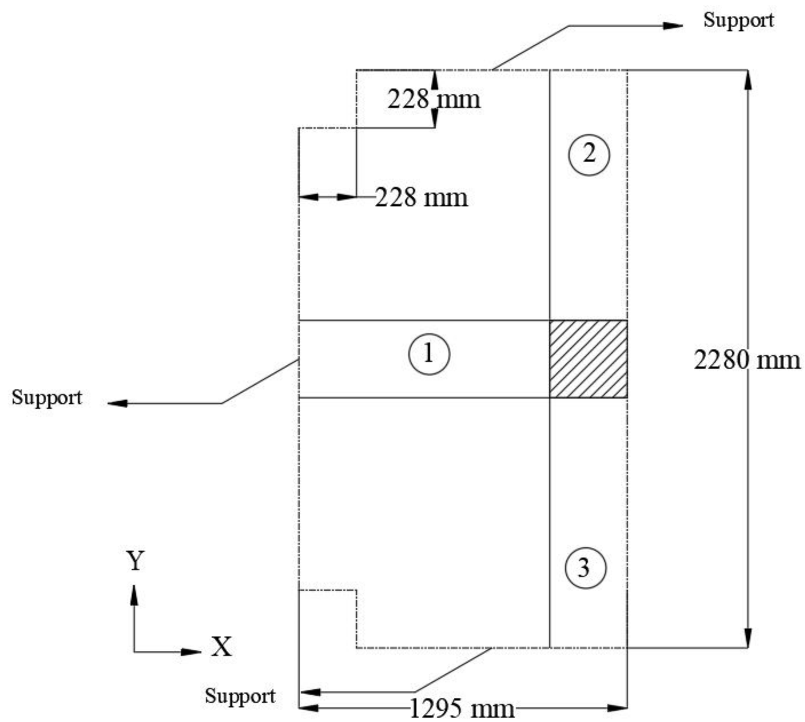
Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$$P_{s2} := 2 \cdot \sqrt{M_{sy} \cdot w_{ACI\_y}} \qquad P_{s2} = 149.056\ kN \qquad P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 539.885\ kN$$



SLAB ES2

STRIP 1 CALCULATIONS

Data: $a_v := 1295\ mm - 305\ mm$ $\quad b := 2280\ mm$ $\quad c1 := 305\ mm$

$b_r := \frac{2280}{2}\ mm$ $\quad a := 1295\ mm - \frac{305}{2}\ mm$ $\quad c2 := 305\ mm$

$d_x := 134\ mm$ $\quad d_y := 134\ mm$ $\quad d := \frac{d_x + d_y}{2}$

Material Properties: $f'c := 33\ MPa$ $\quad fy := 398\ MPa$

Calculations: $a_v = 99\ cm$

$d_x = 13.4\ cm$

$$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\Big\|\; \frac{2\ d_x}{a_v} \quad \text{else} \;\Big\|\; 1$$

$E.F = 1$ Calculation of Enhancement Factor (E.F) due to loads close to supports

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\Big\|\; \text{if } 0 \le \frac{a}{d_x} \le 2.5 \;\Big\|\; 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \;\; \text{else if } \frac{a}{d_x} > 2.5 \;\Big\|\; 2 \cdot \frac{b_r}{b}$$

$$\beta = 1$$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 115.905\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 10 \cdot \left(201.06\ mm^2 \right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.512\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 13.675\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 10 \cdot \left(201.06\ mm^2 \right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.512\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2} \right) \cdot \left(\frac{c2}{b} \right) = 13.675\ kN \cdot m$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{Sup1} := 82.51\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 63.12\ \frac{kN \cdot m}{m} \qquad M_{ext} := 78\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 1.307 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\Big\|\; 1 \;\; \text{else} \;\Big\|\; \lambda_{moment}$$

$$\lambda_{moment} = 1$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 37.783\ kN \cdot m$$

$$P_{s1} := 2\ \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 132.352\ kN$$

STRIP 2 CALCULATIONS

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 18 \cdot \left(201.06\ mm^2\right) \qquad b := 1295\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 39.653\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.733\ kN \cdot m$$

$$A_{sy\_top} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 39.653\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.733\ kN \cdot m$$

$$\lambda_{moment} = 1$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 77.465\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 115.905\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 1156.158\ mm$$

$$l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s2} := \text{if } l > l_s \\ \quad \| \beta \cdot w_{ACI\_y} \cdot l_s \\ \text{else} \\ \quad \| \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s2} = 98.519\ \boldsymbol{kN}$$

$$P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3}$$

$$P = 329.39\ \boldsymbol{kN}$$

SLAB ES5

STRIP 1 CALCULATIONS

Data: $a_v := 1295\ mm - 305\ mm$ $b := 2280\ mm$ $c1 := 305\ mm$

$b_r := \frac{2280}{2}\ mm$ $a := 1295\ mm - \frac{305}{2}\ mm$ $c2 := 305\ mm$

$d_x := 134\ mm$ $d_y := 134\ mm$ $d := \frac{d_x + d_y}{2}$

Material Properties: $f'c := 33\ MPa$ $fy := 398\ MPa$

Calculations: $a_v = 99\ cm$ $d_x = 13.4\ cm$

$$E.F := \text{if } \frac{2\ d_x}{a_v} > 1 \;\Big\|\; \frac{2\ d_x}{a_v} \;\text{ else }\; \Big\|\; 1$$

$E.F = 1$ Calculation of Enhancement Factor (E.F) due to loads close to supports

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\Big\|\; \text{if } 0 \le \frac{a}{d_x} \le 2.5 \;\Big\|\; 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \;\text{ else if } \frac{a}{d_x} > 2.5 \;\Big\|\; 2 \cdot \frac{b_r}{b}$$

$\beta = 1$ Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 115.905\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 10 \cdot \left(201.06\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.512\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 13.675\ kN \cdot m$$

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_top} := 10 \cdot \left(201.06\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.512\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 13.675\ kN \cdot m$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{Sup1} := 82.51\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 63.12\ \frac{kN \cdot m}{m} \qquad M_{ext} := 112\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 1.307 \qquad \lambda_{moment} := \begin{cases} 1 & \text{if } \lambda_{moment} > 1 \\ \lambda_{moment} & \text{else} \end{cases} \qquad \lambda_{moment} = 1$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 42.332\ kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \quad P_{s1} = 140.092\ kN$$

<u>STRIP 2 CALCULATIONS</u>

Because of symmetry, strip 2 and strip 3 will carry the same capacity

Flexural Capacity:

$$A_{sy\_bott} := 18 \cdot \left(201.06\ mm^2\right) \qquad b := 1295\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 39.653\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.733\ kN \cdot m$$

$$A_{sy\_top} := 18 \cdot \left(201.06\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 39.653\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 38.733\ kN \cdot m$$

$$M_{Sup2} := 61.84 \; \frac{kN \cdot m}{m} \qquad M_{Span2} := 22.86 \; \frac{kN \cdot m}{m}$$

$$\lambda_{moment} = 1$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 77.465 \; kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \; mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 115.905 \; \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 1156.158 \; mm$$

$$l_s := \frac{1700}{2} \; mm = 850 \; mm$$

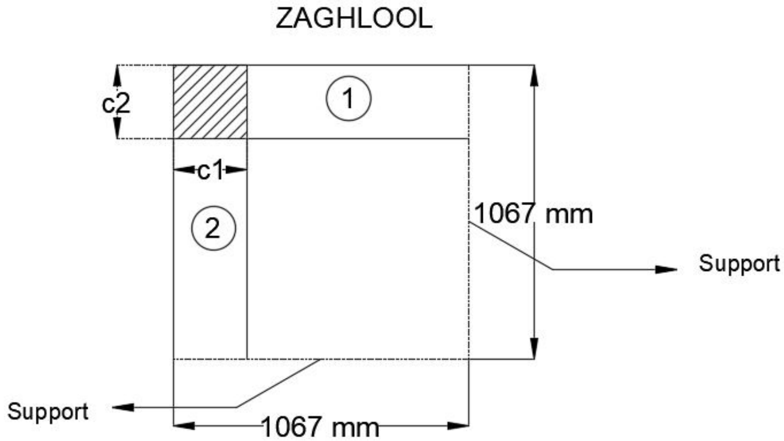
$$P_{s2} := \text{if } l > l_s \quad \| \; \beta \cdot w_{ACI\_y} \cdot l_s \quad \text{else} \quad \| \; \sqrt{2 \; M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s2} = 98.519 \; kN$$

$$P_{s3} := P_{s2}$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 337.13 \; kN$$

ANNEX 5: ZAGHLOOL SLAB CALCULATIONS



SLAB ZI (1)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $b := 1067\ mm$

$d_x := 121\ mm$ $d_y := 121\ mm$ $a := 1067\ mm - \frac{267}{2}\ mm$

$d := \frac{d_x + d_y}{2}$ $d = 12.1\ cm$ $c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 33\ MPa$ $fy := 379\ MPa$

Calculations: $b_r := 1067\ mm - \frac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.75$ Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(\left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m} \right)$$

$$w_{ACI\_x} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 14 \cdot \left(113.1\ mm^2 \right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 20.051\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 16.665\ kN \cdot m$$

$$A_{sx\_top} := 14 \cdot \left(113.1\ mm^2 \right)$$

Support Moment and Span moment where taken from SCIA model of the slab

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 20.051\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2} \right) \cdot \left(\frac{c2}{b} \right) = 16.665\ kN \cdot m$$

$$M_{Sup1} := 24.49\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 57.46\ \frac{kN \cdot m}{m} \qquad M_{ext} := 19\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.426$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.426$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 28.522\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 725.817\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 78.593\ kN$$

STRIP 2 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(113.1\ mm^2\right)$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 17.186\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.468\ kN \cdot m$$

$$A_{sy\_top} := 12 \cdot \left(113.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 17.186\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.468\ kN \cdot m$$

$$\lambda_{moment} = 0.426 \qquad M_{ext} := 19\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 25.39\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 684.801\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s2} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s2} = 74.151\ kN$$

$$P := P_{s1} + P_{s2} \qquad P = 152.744\ kN$$

SLAB ZII (1)

STRIP 1 CALCULATIONS

Data:

$a_v := 1067\ mm - 267\ mm$ $\qquad b := 1067\ mm$

$a := 1067\ mm - \frac{267}{2}\ mm$ $\qquad c1 := 267\ mm$

$d_x := 121\ mm$ $\qquad d_y := 121\ mm$ $\qquad c2 := 267\ mm$

$d := \frac{d_x + d_y}{2}$ $\qquad d = 12.1\ cm$

Material Properties: $f'c := 33\ MPa$ $\qquad fy := 389\ MPa$

Calculations: $b_r := 1067\ mm - \frac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.75$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_bott} := 14 \cdot \left(113.1\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 20.58\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 17.064\ kN \cdot m$$

$$A_{sx\_top} := 14 \cdot \left(113.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 20.58\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 17.064\ kN \cdot m$$

$M_{Sup1} := 38.99 \; \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 102.19 \; \frac{kN \cdot m}{m}$ $\quad M_{ext} := 39 \; kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.382$ $\quad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$ $\quad \lambda_{moment} = 0.382$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 33.333 \; kN \cdot m$

Check for Loaded Length: $\quad l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 784.653 \; mm$

$l_s := 1075 \; mm = 1075 \; mm$

$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2 \; M_{sx} \cdot \beta \cdot w_{ACI\_x}}$ $\quad P_{s1} = 84.964 \; kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 12 \cdot \left(113.1 \; mm^2\right)$

$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 17.64 \; mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.82 \; kN \cdot m$

$A_{sy\_top} := 12 \cdot \left(113.1 \; mm^2\right)$

$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 17.64 \; mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.82 \; kN \cdot m$

$\lambda_{moment} = 0.382$ $\quad M_{ext} := 39 \; kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 30.234 \; kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 747.283\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 80.917\ kN$$

$$P := P_{s1} + P_{s2} \qquad P = 155.069\ kN$$

SLAB ZII (2)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $\quad b := 1067\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad a := 1067\ mm - \dfrac{267}{2}\ mm$

$d := \dfrac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$ $\quad c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 33\ MPa$ $\quad fy := 405\ MPa$

Calculations: $b_r := 1067\ mm - \dfrac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \dfrac{b_r}{b} = 1.75$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 20 \cdot \left(113.1\ mm^2\right)$

$a_1 := \dfrac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 30.609\ mm$

$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \dfrac{a_1}{2}\right) \cdot \left(\dfrac{c2}{b}\right) = 24.23\ kN \cdot m$

Bending moment capacity determined with Whitney's stress block diagram

$A_{sx\_top} := 20 \cdot \left(113.1\ mm^2\right)$

$a_2 := \dfrac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 30.609\ mm$

$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \dfrac{a_2}{2}\right) \cdot \left(\dfrac{c2}{b}\right) = 24.23\ kN \cdot m$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{Sup1} := 48.35\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 135.97\ \frac{kN \cdot m}{m} \qquad M_{ext} := 53\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.356 \qquad \lambda_{moment} := \begin{array}{l} \text{if } \lambda_{moment} > 1 \\ \quad \| \ 1 \\ \text{else} \\ \quad \| \ \lambda_{moment} \end{array} \qquad \lambda_{moment} = 0.356$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 46.108\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 922.84\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \begin{array}{l} \text{if } l > l_s \\ \quad \| \ \beta \cdot w_{ACI\_x} \cdot l_s \\ \text{else} \\ \quad \| \ \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}} \end{array} \qquad P_{s1} = 99.927\ kN$$

STRIP 2 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(113.1\ mm^2\right)$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.365\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 15.38\ kN \cdot m$$

$$A_{sy\_top} := 12 \cdot \left(113.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.365\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 15.38\ kN \cdot m$$

$$\lambda_{moment} = 0.356 \qquad M_{ext} := 53\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 34.111\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 108.282\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 793.756\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 85.949\ kN$$

$$P := P_{s1} + P_{s2}$$

$$P = 160.101\ kN$$

SLAB ZII (3)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $\quad b := 1067\ mm$

$d_x := 118\ mm$ $\quad d_y := 118\ mm$ $\quad a := 1067\ mm - \dfrac{267}{2}\ mm$

$d := \dfrac{d_x + d_y}{2}$ $\quad d = 11.8\ cm$ $\quad c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 28\ MPa$ $\quad fy := 451\ MPa$

Calculations: $b_r := 1067\ mm - \dfrac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \dfrac{b_r}{b} = 1.75$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 98.086\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 16 \cdot \left(201.06\ mm^2\right)$

$a_1 := \dfrac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 57.132\ mm$

$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \dfrac{a_1}{2}\right) \cdot \left(\dfrac{c2}{b}\right) = 32.469\ kN \cdot m$

Bending moment capacity determined with Whitney's stress block diagram

$A_{sx\_top} := 16 \cdot \left(201.06\ mm^2\right)$

$a_2 := \dfrac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 57.132\ mm$

$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \dfrac{a_2}{2}\right) \cdot \left(\dfrac{c2}{b}\right) = 32.469\ kN \cdot m$

$M_{Sup1} := 46.62 \frac{kN \cdot m}{m}$ $M_{Span1} := 141.67 \frac{kN \cdot m}{m}$ $M_{ext} := 58\ kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.329$ $\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\|\; 1 \;\text{else}\; \|\; \lambda_{moment}$ $\lambda_{moment} = 0.329$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 57.668\ kN \cdot m$

Check for Loaded Length: $l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 1084.368\ mm$

$l_s := 1075\ mm = 1075\ mm$

$P_{s1} := \text{if } l > l_s \;\|\; \beta \cdot w_{ACI\_x} \cdot l_s \;\text{else}\; \|\; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$ $P_{s1} = 105.443\ kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 14 \cdot (201.06\ mm^2)$

$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 49.991\ mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 29.545\ kN \cdot m$

$A_{sy\_top} := 14 \cdot (201.06\ mm^2)$

$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 49.991\ mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 29.545\ kN \cdot m$

$\lambda_{moment} = 0.329$ $M_{ext} := 58\ kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 53.781\ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 98.086\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = \left(1.047 \cdot 10^{3}\right)\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 102.715\ kN$$

$$P := P_{s1} + P_{s2}$$

$$P = 176.866\ kN$$

SLAB ZII (6)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $b := 1067\ mm$

$d_x := 121\ mm$ $d_y := 121\ mm$ $a := 1067\ mm - \frac{267}{2}\ mm$

$d := \frac{d_x + d_y}{2}$ $d = 12.1\ cm$ $c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 34\ MPa$ $fy := 381\ MPa$

Calculations: $b_r := 1067\ mm - \frac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.75$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$w_{ACI\_x} = 109.91\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

Bending moment capacity determined with Whitney's stress block diagram

$A_{sx\_bott} := 14 \cdot \left(113.1\ mm^2\right)$

$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.564\ mm$

$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 16.79\ kN \cdot m$

$A_{sx\_top} := 14 \cdot \left(113.1\ mm^2\right)$

$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.564\ mm$

$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 16.79\ kN \cdot m$

$M_{Sup1} := 16.18\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 80.01\ \frac{kN \cdot m}{m}$ $\quad M_{ext} := 39\ kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.202$ $\quad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \ \| \ 1 \ \text{else} \ \| \ \lambda_{moment}$ $\quad \lambda_{moment} = 0.202$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 29.944\ kN \cdot m$

Check for Loaded Length: $l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 738.16\ mm$

$l_s := 1075\ mm = 1075\ mm$

$P_{s1} := \text{if } l > l_s \ \| \ \beta \cdot w_{ACI\_x} \cdot l_s \ \text{else} \ \| \ \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$ $\quad P_{s1} = 81.131\ kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 12 \cdot \left(113.1\ mm^2\right)$

$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.769\ mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.572\ kN \cdot m$

$A_{sy\_top} := 12 \cdot \left(113.1\ mm^2\right)$

$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.769\ mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.572\ kN \cdot m$

$\lambda_{moment} = 0.202$ $\quad M_{ext} := 39\ kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 27.278\ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 109.91\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 704.531\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 77.435\ kN$$

$$P := P_{s1} + P_{s2} \qquad P = 151.587\ kN$$

SLAB ZII (8)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $b := 1067\ mm$

$d_x := 121\ mm$ $d_y := 121\ mm$ $a := 1067\ mm - \frac{267}{2}\ mm$

$d := \frac{d_x + d_y}{2}$ $d = 12.1\ cm$ $c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 36\ MPa$ $fy := 382\ MPa$

Calculations: $b_r := 1067\ mm - \frac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.75$ Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear: $w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$

$w_{ACI\_x} = 113.097\ \frac{kN}{m}$ Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity: $A_{sx\_bott} := 14 \cdot \left(113.1\ mm^2\right)$ Bending moment capacity determined with Whitney's stress block diagram

$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.525\ mm$

$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 16.912\ kN \cdot m$

$A_{sx\_top} := 14 \cdot \left(113.1\ mm^2\right)$

$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.525\ mm$

$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 16.912\ kN \cdot m$

$M_{Sup1} := 33.13\ \frac{kN \cdot m}{m}$ $M_{Span1} := 119.60\ \frac{kN \cdot m}{m}$ $M_{ext} := 39\ kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.277$ $\lambda_{moment} := \text{if } \lambda_{moment} > 1 \ \| 1 \ \text{else} \ \| \lambda_{moment}$ $\lambda_{moment} = 0.277$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 31.356\ kN \cdot m$

Check for Loaded Length: $l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 744.648\ mm$

$l_s := 1075\ mm = 1075\ mm$

$P_{s1} := \text{if } l > l_s \ \| \beta \cdot w_{ACI\_x} \cdot l_s \ \text{else} \ \| \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$ $P_{s1} = 84.217\ kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 12 \cdot (113.1\ mm^2)$

$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.879\ mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.668\ kN \cdot m$

$A_{sy\_top} := 12 \cdot (113.1\ mm^2)$

$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.879\ mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.668\ kN \cdot m$

$\lambda_{moment} = 0.277$ $M_{ext} := 39\ kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 28.49\ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 113.097\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 709.801\ mm$$

$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 80.276\ kN$$

$$P := P_{s1} + P_{s2} \qquad P = 154.428\ kN$$

SLAB ZIII (1)

STRIP 1 CALCULATIONS

Data: $a_v := 1067\ mm - 267\ mm$ $\quad b := 1067\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad a := 1067\ mm - \frac{267}{2}\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$ $\quad c1 := 267\ mm$

$c2 := 267\ mm$

Material Properties: $f'c := 34\ MPa$ $\quad fy := 379\ MPa$

Calculations: $b_r := 1067\ mm - \frac{267}{2}\ mm = 933.5\ mm$

$\beta := 2 \cdot \frac{b_r}{b} = 1.75$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

$\beta := 1$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 109.91\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

Bending moment capacity determined with Whitney's stress block diagram

$$A_{sx\_bott} := 14 \cdot \left(113.1\ mm^2\right)$$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.461\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 16.709\ kN \cdot m$$

$$A_{sx\_top} := 14 \cdot \left(113.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 19.461\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2} \right) \cdot \left(\frac{c2}{b} \right) = 16.709\ kN \cdot m$$

$M_{Sup1} := 42.82 \ \frac{kN \cdot m}{m}$ $M_{Span1} := 125.16 \ \frac{kN \cdot m}{m}$ $M_{ext} := 132 \ kN \cdot m \cdot \frac{c2}{b}$

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.342$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \ \| \ 1 \ \text{else} \ \| \ \lambda_{moment}$$

$\lambda_{moment} = 0.342$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 55.457 \ kN \cdot m$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = \left(1.005 \cdot 10^{3}\right) \ mm$$

$l_s := 1075 \ mm = 1075 \ mm$

$$P_{s1} := \text{if } l > l_s \ \| \ \beta \cdot w_{ACI\_x} \cdot l_s \ \text{else} \ \| \ \sqrt{2 \ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$P_{s1} = 110.41 \ kN$

STRIP 2 CALCULATIONS

Flexural Capacity:

$A_{sy\_bott} := 12 \cdot \left(113.1 \ mm^{2}\right)$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.681 \ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.501 \ kN \cdot m$$

$A_{sy\_top} := 12 \cdot \left(113.1 \ mm^{2}\right)$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.681 \ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 14.501 \ kN \cdot m$$

$\lambda_{moment} = 0.342$ $M_{ext} := 53 \ kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 32.725 \ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 109.91\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sy}}{\beta \cdot w_{ACI\_y}}} = 771.672\ mm$$

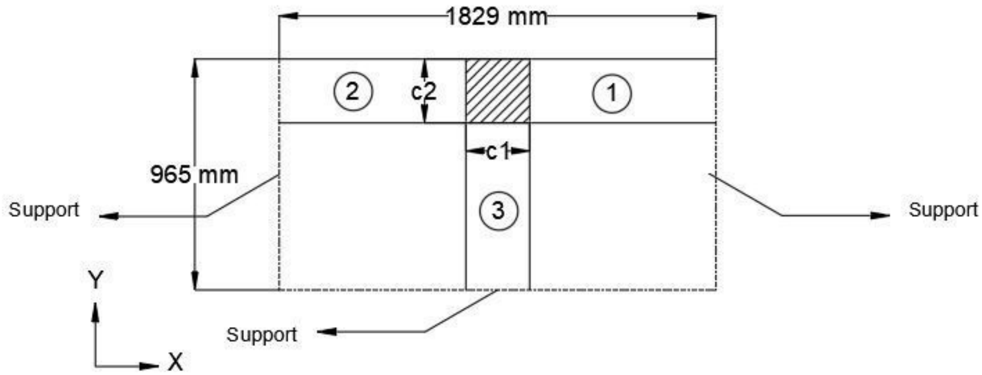
$$l_s := 1075\ mm = 1075\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_y} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sy} \cdot \beta \cdot w_{ACI\_y}}$$

$$P_{s1} = 84.815\ kN$$

$$P := P_{s1} + P_{s2}$$

$$P = 158.966\ kN$$



SLAB ZIV (1)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm$ $\quad a := \frac{1829}{2}\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$ $\quad c2 := 267\ mm$

Material Properties: $f'c := 27\ MPa$ $\quad fy := 476\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \left\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \left\| 2 \cdot \frac{b_r}{b} \right. \end{array} \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 97.945\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 22 \cdot \left(113.1\ mm^2\right)$$

$b := 965\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 53.479\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 30.889\ kN \cdot m$$

$$A_{sx\_top} := 22 \cdot \left(113.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 53.479\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 30.889\ kN \cdot m$$

$$M_{Sup1} := 28.60\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 31.97\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.895$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.895$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 58.522\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 1093.164\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 83.253\ kN$$

$$P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 13 \cdot \left(113.1\ mm^2\right) \qquad b := 1829\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.673\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.51\ kN \cdot m$$

$$A_{sy\_top} := 13 \cdot \left(113.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 16.673\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.51\ kN \cdot m$$

$$\lambda_{moment} = 0.895 \qquad M_{ext} := -48\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 14.801\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 97.945\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$$P_{s3} := 2\sqrt{M_{sy} \cdot w_{ACI\_y}} \qquad P_{s3} = 76.148\ kN$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 242.654\ kN$$

SLAB ZV (1)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm$ $\quad a := \frac{1829}{2}\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$ $\quad c2 := 267\ mm$

Material Properties: $f'c := 34\ MPa$ $\quad fy := 474\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2}\ \left\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \left\| 2 \cdot \frac{b_r}{b} \right. \end{array} \right.$$

$\beta = 1$ Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$w_{ACI\_x} = 109.91\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 22 \cdot \left(113.1\ mm^2\right)$

$b := 965\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 42.29\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 32.585\ kN \cdot m$$

$$A_{sx\_top} := 22 \cdot \left(113.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 42.29\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 32.585\ kN \cdot m$$

$$M_{Sup1} := 44.18\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 52.72\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.838$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.838$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 59.892\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 1043.948\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 93.424\ kN$$

$$P_{s2} := P_{s1}$$

<u>STRIP 3 CALCULATIONS</u>

Flexural Capacity:

$$A_{sy\_bott} := 13 \cdot \left(113.1\ mm^2\right) \qquad b := 1829\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.185\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.64\ kN \cdot m$$

$$A_{sy\_top} := 13 \cdot \left(113.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.185\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.64\ kN \cdot m$$

$\lambda_{moment} = 0.838$ $\qquad M_{ext} := -48\ kN \cdot m \cdot \frac{c1}{b}$

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 14.387\ kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$w_{ACI\_y} = 109.91\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$P_{s3} := 2\ \sqrt{M_{sy} \cdot w_{ACI\_y}}$ $\qquad P_{s3} = 79.529\ kN$

$P := P_{s1} + P_{s2} + P_{s3}$ $\qquad P = 266.377\ kN$

SLAB ZV (2)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm$ $\quad a := \frac{1829}{2}\ mm$

$d_x := 121\ mm$ $\quad d_y := 121\ mm$ $\quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2}$ $\quad d = 12.1\ cm$ $\quad c2 := 267\ mm$

Material Properties: $f'c := 40\ MPa$ $\quad fy := 474\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \left\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \left\| 2 \cdot \frac{b_r}{b} \right. \end{array} \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 119.214\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 32 \cdot \left(113.1\ mm^2\right)$$

$b := 965\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 52.286\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 45.024\ kN \cdot m$$

$$A_{sx\_top} := 32 \cdot (113.1\ mm^2)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 52.286\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 45.024\ kN \cdot m$$

$$M_{Sup1} := 54.18\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 59.43\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.912$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.912$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 86.071\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = \left(1.202 \cdot 10^3\right)\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 101.332\ kN$$

$$P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 14 \cdot (113.1\ mm^2) \qquad b := 1829\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.069\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 12.596\ kN \cdot m$$

$$A_{sy\_top} := 14 \cdot (113.1\ mm^2)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 12.069\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 12.596\ kN \cdot m$$

$$\lambda_{moment} = 0.912 \qquad M_{ext} := -94\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 10.357\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 119.214\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$$P_{s3} := 2\ \sqrt{M_{sy} \cdot w_{ACI\_y}} \qquad P_{s3} = 70.277\ kN$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 272.941\ kN$$

SLAB ZV (3)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm \quad a := \frac{1829}{2}\ mm$

$d_x := 118\ mm \quad d_y := 118\ mm \quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2} \quad d = 11.8\ cm \quad c2 := 267\ mm$

Material Properties: $f'c := 39\ MPa \quad fy := 475\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \left\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \left\| 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \right. \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \left\| 2 \cdot \frac{b_r}{b} \right. \end{array} \right.$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 115.761\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 24 \cdot \left(201.1\ mm^2 \right)$ $\quad b := 965\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 71.665\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2} \right) \cdot \left(\frac{c2}{b} \right) = 52.12\ kN \cdot m$$

$$A_{sx\_top} := 24 \cdot \left(201.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 71.665\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 52.12\ kN \cdot m$$

$$M_{Sup1} := 56.88\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 65.16\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.873$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\|\; 1 \;\; \text{else} \;\|\; \lambda_{moment}$$

$$\lambda_{moment} = 0.873$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 97.616\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = \left(1.299 \cdot 10^3\right)\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\|\; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\|\; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 98.397\ kN$$

$$P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 12 \cdot \left(201.1\ mm^2\right) \qquad b := 1829\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.906\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 18.164\ kN \cdot m$$

$$A_{sy\_top} := 12 \cdot \left(201.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 18.906\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 18.164\ kN \cdot m$$

$$\lambda_{moment} = 0.873 \qquad M_{ext} := -104\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} + M_{ext} = 18.837\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 115.761\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$$P_{s3} := 2\ \sqrt{M_{sy} \cdot w_{ACI\_y}} \qquad P_{s3} = 93.394\ kN$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 290.187\ kN$$

SLAB ZV (6)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm \quad a := \frac{1829}{2}\ mm$

$d_x := 121\ mm \quad d_y := 121\ mm \quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2} \quad d = 12.1\ cm \quad c2 := 267\ mm$

Material Properties: $f'c := 34\ MPa \quad fy := 476\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\; \Bigg\| \begin{array}{l} \text{if } 0 \le \frac{a}{d_x} \le 2.5 \\ \quad \| \; 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \\ \text{else if } \frac{a}{d_x} > 2.5 \\ \quad \| \; 2 \cdot \frac{b_r}{b} \end{array}$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 109.91\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 22 \cdot \left(113.1\ mm^2\right)$ $\quad b := 965\ mm$

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 42.469\ mm$$

Bending moment capacity determined with Whitney's stress block diagram

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 32.693\ kN \cdot m$$

$$A_{sx\_top} := 22 \cdot (113.1\ mm^2)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 42.469\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 32.693\ kN \cdot m$$

$$M_{Sup1} := 48.65\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 115.10\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.423$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\|\; 1 \;\text{ else }\;\|\; \lambda_{moment}$$

$$\lambda_{moment} = 0.423$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 46.512\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 919.979\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\|\; \beta \cdot w_{ACI\_x} \cdot l_s \;\text{ else }\;\|\; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 93.424\ kN$$

$$P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Flexural Capacity:

$$A_{sy\_bott} := 13 \cdot (113.1\ mm^2) \qquad b := 1829\ mm$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.24\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.686\ kN \cdot m$$

$$A_{sy\_top} := 13 \cdot (113.1\ mm^2)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.24\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 11.686\ kN \cdot m$$

$$\lambda_{moment} = 0.423 \qquad M_{ext} := -88\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + M_{hogy} + M_{ext} = 10.525 \ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 109.91 \ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

Dead Load Effect Neglected due to Testing Setup which is vertical

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot w_{ACI\_y}} \qquad P_{s3} = 68.025 \ kN$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 254.872 \ kN$$

SLAB ZVI (1)

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1829}{2}\ mm - \frac{267}{2}\ mm$ $\quad b := 1829\ mm$

$b_r := \frac{1829}{2}\ mm \quad a := \frac{1829}{2}\ mm$

$d_x := 121\ mm \quad d_y := 121\ mm \quad c1 := 267\ mm$

$d := \frac{d_x + d_y}{2} \quad d = 12.1\ cm \quad c2 := 267\ mm$

Material Properties: $f'c := 26\ MPa \quad fy := 476\ MPa$

$$\beta := \text{if } 0 \le \frac{b_r}{b} \le \frac{1}{2} \;\Bigg\|\; \text{if } 0 \le \frac{a}{d_x} \le 2.5 \;\Big\|\; 0.8 \cdot \frac{a}{d_x} \cdot \frac{b_r}{b} \;\;\text{else if } \frac{a}{d_x} > 2.5 \;\Big\|\; 2 \cdot \frac{b_r}{b}$$

$\beta = 1$

Calculation of Torsion Factor (β) for loads close to the support and asymmetric conditions

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$w_{ACI\_x} = 96.114\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 22 \cdot \left(113.1\ mm^2\right)$ $\quad b := 965\ mm$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 55.536\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 30.552\ kN \cdot m$$

$$A_{sx\_top} := 22 \cdot \left(113.1\ mm^2\right)$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 55.536\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 30.552\ kN \cdot m$$

$$M_{Sup1} := 45.19\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 60.98\ \frac{kN \cdot m}{m}$$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.741$$

$$\lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment}$$

$$\lambda_{moment} = 0.741$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} = 53.193\ kN \cdot m$$

Check for Loaded Length:

$$l := \sqrt{\frac{2 \cdot M_{sx}}{\beta \cdot w_{ACI\_x}}} = 1052.084\ mm \qquad l_s := \frac{1700}{2}\ mm = 850\ mm$$

$$P_{s1} := \text{if } l > l_s \;\; \| \; \beta \cdot w_{ACI\_x} \cdot l_s \;\; \text{else} \;\; \| \; \sqrt{2\ M_{sx} \cdot \beta \cdot w_{ACI\_x}}$$

$$P_{s1} = 81.697\ kN$$

$$P_{s2} := P_{s1}$$

<u>STRIP 3 CALCULATIONS</u>

Flexural Capacity:

$$A_{sy\_bott} := 13 \cdot \left(113.1\ mm^2\right)$$

$$a_3 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 32.817\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_3}{2}\right) \cdot \left(\frac{c1}{b}\right) = 20.253\ kN \cdot m$$

$$A_{sy\_top} := 13 \cdot \left(113.1\ mm^2\right)$$

$$a_4 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 32.817\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_4}{2}\right) \cdot \left(\frac{c1}{b}\right) = 20.253\ kN \cdot m$$

$$\lambda_{moment} = 0.741 \qquad M_{ext} := -107\ kN \cdot m \cdot \frac{c1}{b}$$

$$M_{sy} := M_{sagy} + M_{hogy} + M_{ext} = 10.901\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 96.114\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

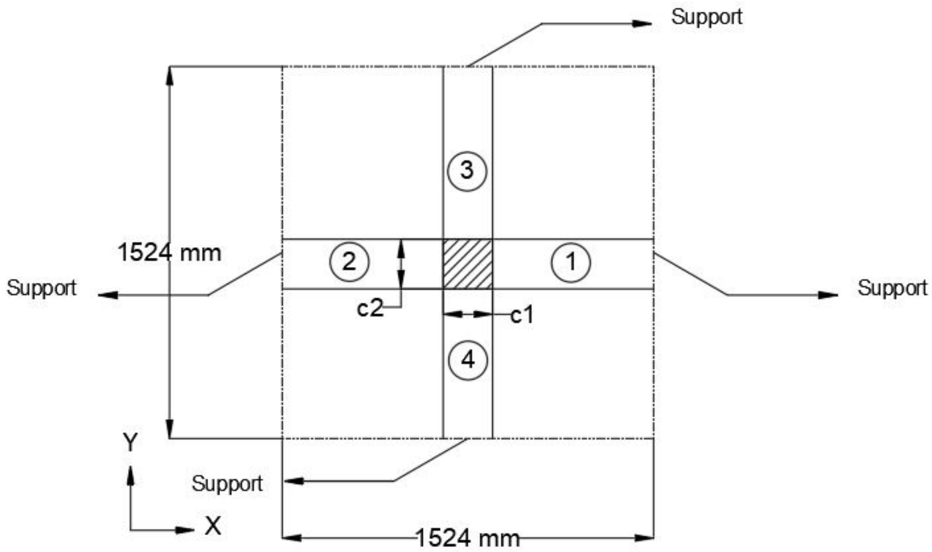
Dead Load Effect Neglected due to Testing Setup which is vertical

$$a_m := 673.47\ mm \qquad L := 1829\ mm$$

$$P_{s3} := \sqrt{2 \cdot \beta \cdot \left(\frac{L}{L - a_m} \right) \cdot M_{sy} \cdot w_{ACI\_y}} \qquad P_{s3} = 57.592\ kN$$

$$P := P_{s1} + P_{s2} + P_{s3} \qquad P = 220.985\ kN$$

ANNEX 6: ANIS SLAB CALCULATIONS



SLAB B.3

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm$ $b := 1524\ mm$ $c1 := 203\ mm$

$b_r := 0$ $a := \frac{1524}{2}\ mm$ $c2 := 203\ mm$

$d_x := 76\ mm$ $d_y := 76\ mm$ $d := \frac{d_x + d_y}{2}$ $d = 76\ mm$

Material Properties:

$f'c := 38\ MPa$ $fy := 330\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$w_{ACI\_x} = 85.22\ \frac{kN}{m}$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$A_{sx\_bott} := 18 \cdot \left(122.7\ mm^2\right)$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.806\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.66\ kN \cdot m$$

$$A_{sx\_top} := 18\ (122.7)\ mm^2$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.806\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.66\ kN \cdot m$$

$$M_{Sup1} := 13.38\ \frac{kN \cdot m}{m} \qquad M_{Span1} := 40.2\ \frac{kN \cdot m}{m} \qquad M_{ext} := -18\ kN \cdot m \cdot \frac{c2}{b}$$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.333 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \ \| \ 1 \ \text{else} \ \| \ \lambda_{moment} \qquad \lambda_{moment} = 0.333$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 6.478\ kN \cdot m$$

$$P_{s1} := 2\ \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 46.994\ kN \qquad P_{s2} := P_{s1}$$

<u>STRIP 3 CALCULATIONS</u>

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$$a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm \qquad b := 1524\ mm$$

$$b_r := 0 \qquad a := \frac{1524}{2}\ mm \qquad c1 := 203\ mm \qquad c2 := 203\ mm$$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.806\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.66\ kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.806\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.66\ kN \cdot m$$

$$\lambda_{moment} = 0.333$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 8.876\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 85.22\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 0.25\ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 54.926\ kN \qquad P_{s4} := P_{s3}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 203.838\ kN$$

SLAB B.4

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm$ $\quad b := 1524\ mm$ $\quad c1 := 203\ mm$

$b_r := 0$

$a := \frac{1524}{2}\ mm$ $\quad c2 := 203\ mm$

$d_x := 76\ mm$ $\quad d_y := 76\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 76\ mm$

Material Properties:

$f'c := 37\ MPa$ $\quad fy := 330\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 84.091\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 18 \cdot \left(122.7\ mm^2\right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.206\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.64\ kN \cdot m$$

$$A_{sx\_top} := 18\ (122.7)\ mm^2$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.206\ mm$$

Support Moment and Span moment where taken from SCIA model of the slab

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.64\ kN \cdot m$$

$M_{Sup1} := 10.37\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 32.00\ \frac{kN \cdot m}{m}$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.324 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \;\; \| \; 1 \;\; \text{else} \;\; \| \; \lambda_{moment} \qquad \lambda_{moment} = 0.324$$

$$M_{ext} := -26 \; kN \cdot m \cdot \frac{c2}{b}$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 5.329 \; kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 42.337 \; kN \qquad P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$$a_v := \frac{1524}{2} \; mm - \frac{203}{2} \; mm \qquad b := 1524 \; mm$$

$$b_r := 0$$

$$a := \frac{1524}{2} \; mm \qquad c1 := 203 \; mm \qquad c2 := 203 \; mm$$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.206 \; mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.64 \; kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.206 \; mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.64 \; kN \cdot m$$

$$\lambda_{moment} = 0.324$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 8.792 \; kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \; mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 84.091\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 0.25\ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 54.3\ kN \qquad P_{s3} := P_{s4}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 194.525\ kN$$

SLAB B.5

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm$ $\quad b := 1524\ mm$ $\quad c1 := 203\ mm$

$b_r := 0$ $\quad a := \frac{1524}{2}\ mm$ $\quad c2 := 203\ mm$

$d_x := 76\ mm$ $\quad d_y := 76\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 76\ mm$

Material Properties:

$f'c := 36\ MPa$ $\quad fy := 330\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 82.947\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 18 \cdot \left(122.7\ mm^2\right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.629\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.62\ kN \cdot m$$

$$A_{sx\_top} := 18\ (122.7)\ mm^2$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.629\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.62\ kN \cdot m$$

$M_{Sup1} := 13.73\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 30.25\ \frac{kN \cdot m}{m}$

Support Moment and Span moment where taken from SCIA model of the slab

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.454 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \; \| \; 1 \; \text{else} \; \| \; \lambda_{moment} \qquad \lambda_{moment} = 0.454$$

$$M_{ext} := -39\ kN \cdot m \cdot \frac{c2}{b}$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 4.429\ kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 38.335\ kN \qquad P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$$a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm \qquad b := 1524\ mm$$

$$b_r := 0$$

$$a := \frac{1524}{2}\ mm \qquad c1 := 203\ mm \qquad c2 := 203\ mm$$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.629\ mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.62\ kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 15.629\ mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.62\ kN \cdot m$$

$$\lambda_{moment} = 0.454$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 9.624\ kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 82.947\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 0.25\ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 56.423\ kN \qquad P_{s3} := P_{s4}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 186.522\ kN$$

SLAB B.6

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm$ $\quad b := 1524\ mm$ $\quad c1 := 203\ mm$

$b_r := 0$ $\quad a := \frac{1524}{2}\ mm$ $\quad c2 := 203\ mm$

$d_x := 76\ mm$ $\quad d_y := 76\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 76\ mm$

Material Properties:

$f'c := 39\ MPa$ $\quad fy := 330\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 86.334\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Flexural Capacity:

$$A_{sx\_bott} := 18 \cdot \left(122.7\ mm^2\right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.427\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.678\ kN \cdot m$$

$$A_{sx\_top} := 18\ (122.7)\ mm^2$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.427\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.678\ kN \cdot m$$

$M_{Sup1} := 16.22\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 29.17\ \frac{kN \cdot m}{m}$

Support Moment and Span moment where taken from SCIA model of the slab

$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.556$ $\lambda_{moment} := \text{if } \lambda_{moment} > 1 \; \| \; 1 \; \text{else} \; \| \; \lambda_{moment}$ $\lambda_{moment} = 0.556$

$M_{ext} := -54 \; kN \cdot m \cdot \frac{c2}{b}$

$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 3.198 \; kN \cdot m$

$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}}$ $P_{s1} = 33.234 \; kN$ $P_{s2} := P_{s1}$

STRIP 3 CALCULATIONS

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$a_v := \frac{1524}{2} \; mm - \frac{203}{2} \; mm$ $b := 1524 \; mm$

$b_r := 0$

$a := \frac{1524}{2} \; mm$ $c1 := 203 \; mm$ $c2 := 203 \; mm$

Flexural Capacity:

$A_{sy\_bott} := A_{sx\_bott}$

$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.427 \; mm$

$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2} \right) \cdot \left(\frac{c1}{b} \right) = 6.678 \; kN \cdot m$

$A_{sy\_top} := A_{sx\_top}$

$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 14.427 \; mm$

$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2} \right) \cdot \left(\frac{c1}{b} \right) = 6.678 \; kN \cdot m$

$\lambda_{moment} = 0.556$

Support Moment and Span moment where taken from SCIA model of the slab

$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 10.391 \; kN \cdot m$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \; mm}{d} \right)^{\frac{1}{3}} \right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 86.334 \ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 0.25 \ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 59.817 \ kN \qquad P_{s3} := P_{s4}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 176.32 \ kN$$

SLAB B.7

STRIP 1 CALCULATIONS

Because of symmetry, strip 1 and strip 2 will carry the same capacity

Data: $a_v := \frac{1524}{2}\ mm - \frac{203}{2}\ mm$ $\quad b := 1524\ mm$ $\quad c1 := 203\ mm$

$b_r := 0$

$a := \frac{1524}{2}\ mm$ $\quad c2 := 203\ mm$

$d_x := 76\ mm$ $\quad d_y := 76\ mm$ $\quad d := \frac{d_x + d_y}{2}$ $\quad d = 76\ mm$

Material Properties:

$f'c := 42\ MPa$ $\quad fy := 330\ MPa$

One - Way Shear:

$$w_{ACI\_x} := \left(0.166 \cdot \frac{d_y}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100\ mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_x} = 89.593\ \frac{kN}{m}$$

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Flexural Capacity:

$$A_{sx\_bott} := 18 \cdot \left(122.7\ mm^2\right)$$

Bending moment capacity determined with Whitney's stress block diagram

$$a_1 := \frac{A_{sx\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.396\ mm$$

$$M_{sagx} := A_{sx\_bott} \cdot fy \cdot \left(d_x - \frac{a_1}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.728\ kN \cdot m$$

$$A_{sx\_top} := 188\ (122.7)\ mm^2$$

$$a_2 := \frac{A_{sx\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 139.915\ mm$$

$$M_{hogx} := A_{sx\_top} \cdot fy \cdot \left(d_x - \frac{a_2}{2}\right) \cdot \left(\frac{c2}{b}\right) = 6.127\ kN \cdot m$$

$M_{Sup1} := 12.23\ \frac{kN \cdot m}{m}$ $\quad M_{Span1} := 25.99\ \frac{kN \cdot m}{m}$

$$\lambda_{moment} := \frac{M_{Sup1}}{M_{Span1}} = 0.471 \qquad \lambda_{moment} := \text{if } \lambda_{moment} > 1 \; \| \; 1 \; \text{else} \; \| \; \lambda_{moment} \qquad \lambda_{moment} = 0.471$$

$$M_{ext} := -66 \; kN \cdot m \cdot \frac{c2}{b}$$

$$M_{sx} := M_{sagx} + \lambda_{moment} \cdot M_{hogx} + M_{ext} = 0.82 \; kN \cdot m$$

$$P_{s1} := 2 \cdot \sqrt{M_{sx} \cdot w_{ACI\_x}} \qquad P_{s1} = 17.141 \; kN \qquad P_{s2} := P_{s1}$$

STRIP 3 CALCULATIONS

Because of symmetry, strip 3 and strip 4 will carry the same capacity

Data:

$$a_v := \frac{1524}{2} \; mm - \frac{203}{2} \; mm \qquad b := 1524 \; mm$$

$$b_r := 0$$

$$a := \frac{1524}{2} \; mm \qquad c1 := 203 \; mm \qquad c2 := 203 \; mm$$

Flexural Capacity:

$$A_{sy\_bott} := A_{sx\_bott}$$

$$a_5 := \frac{A_{sy\_bott} \cdot fy}{0.85 \cdot f'c \cdot b} = 13.396 \; mm$$

$$M_{sagy} := A_{sy\_bott} \cdot fy \cdot \left(d_y - \frac{a_5}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.728 \; kN \cdot m$$

$$A_{sy\_top} := A_{sx\_top}$$

$$a_6 := \frac{A_{sy\_top} \cdot fy}{0.85 \cdot f'c \cdot b} = 139.915 \; mm$$

$$M_{hogy} := A_{sy\_top} \cdot fy \cdot \left(d_y - \frac{a_6}{2}\right) \cdot \left(\frac{c1}{b}\right) = 6.127 \; kN \cdot m$$

$$\lambda_{moment} = 0.471$$

$$M_{sy} := M_{sagy} + \lambda_{moment} \cdot M_{hogy} = 9.611 \; kN \cdot m$$

One - Way Shear:

$$w_{ACI\_y} := \left(0.166 \cdot \frac{d_x}{mm} \cdot \sqrt{\frac{f'c}{MPa}} \cdot \left(\frac{100 \; mm}{d}\right)^{\frac{1}{3}}\right) \cdot \frac{kN}{m}$$

$$w_{ACI\_y} = 89.593\ \frac{kN}{m}$$

Size effect consideration in expression of one way shear capacity at the interface between the strip and quadrant

Dead Load Effect:

$$v_{DL} := 0.25\ \frac{kN}{m}$$

$$P_{s3} := 2 \cdot \sqrt{M_{sy} \cdot \left(w_{ACI\_y} - v_{DL}\right)} \qquad P_{s3} = 58.607\ kN \qquad P_{s3} := P_{s4}$$

$$P := P_{s1} + P_{s2} + P_{s3} + P_{s4} \qquad P = 144.134\ kN$$