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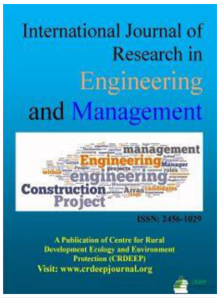

<u>**Full Length Research Paper**</u>

Parametric Study of Multiplanar Tubular KK-Joints

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ABSTRACT

A parametric study is presented for the ultimate capacity of hollow circular sections in multiplanar KK-joints andtheir corresponding Uniplanar K-joints where developed, which are commonly used in onshore and offshore structures. However, the design of multi-planar joints is not covered by international design codes, design guides, and not addressed extensively in previous researchers. This study was held using a well-calibrated and validated finite-element model, the joints were designed with longitudinal and transversal gap region between the diagonal braces and the connections were subjected to symmetrical axial loading. Analyses were performed using the finite element program (ANSYS APDL). In all, 96 joints were analyzed to investigate the effect of the various geometric parameters on correlation factor (Pu'=KK Pu/ K Pu) . The resistance of KK and K connections where compared as determined using numerical analyses, to predict the resistance of KK connections based on geometric parameters and the corresponding resistance of the uniplanar K connection.

List of notations

Db	*brace diameter*
Dc	*chord diameter*
E	*Young's modulus (210,000 MPa)*
gl	*longitudinal gap between brace toes*
gt	*transverse gap between brace toes*
$Pu\ KK$	*ultimate capacity of the Multiplanar joint from the finite element analysis*
$Pu\ K$	*ultimate capacity of the Uniplanar joint from the finite element analysis*
Pu'	*KK Pu / K Pu correlation factor for the resistance*
Tb	*brace wall thickness*
Tc	*chord wall thickness*
β	*db/ dc (brace-to-chord diameter ratio)*
φ	*angle between K-planes*
θ	*angle between brace and chord*
τ	*tb/ tc (brace-to-chord thickness ratio)*
ζl	*gl/ dc (in-plane gap/overlap to chord diameter ratio)*
ζt	*gt/ dc (out-of-plane gap/overlap to chord diameter ratio)*

Introduction

Tubular joints in circular hollow sections used in structures like towers, masts, long-span roofs, and offshore drilling platforms are generally of multiplanar configurations. They are composed of members lying in several planes. The design of multiplanar tubular connections traditionally follows guidelines derived from the interpretation of results on strength testing of planar joints. The normal practice adopted is to treat each plane in isolation and design with no reference to the effect of the presence of loads in the out of plane braces. The standard practice is to treat every plane separately and then multiply the resistance by a unique correlation coefficient that is not depend on the joint geometry.

Study of multiplanar effects on static strength of tubular joints started in the early 1980s when a series of multiplanar KK-joints were tested in Japan (Makino et al. 1984). Several studies were engaged worldwide because of the interest in multiplanar joints development. Important studies on KK joints include Mouty and Rondal (1990), Makino et al. (1993), and Paul et al. (1992). Makino et al. (1984) 20 KK joints were tested and identified two types of failure modes occurring when the connection was symmetrically loaded.

Joints having a small transversal gap fail in mode 1, in which the diagonal braces act together without deformation near the transversal gap region. Other joints with mode 2 failure got too much deformation near the transversal gap region. Wilmshurst and Lee (1995) approached a finite element analysis for KK connections. After that a parametric study of KK joints is presented (1996) and also a study for symmetrical loaded KK joints (1997). Uniplanar and multiplanar joints design methodologies are performed within the CIDECT manual (Wardenier et al. 2008), Eurocode 3 (2005), Brazilian NBR 16239 (2013), and Wardenier et al. (2010). The mechanical behavior of joints, which is adopted worldwide, was estimated using numerical simulation.

The most recent IIW (2012) and ISO 14346 (2013) recommended a numerical data which is verified using experimental results (van der Vegte and Wardenier 2014) for the circular hollow section uniplanar K joint.

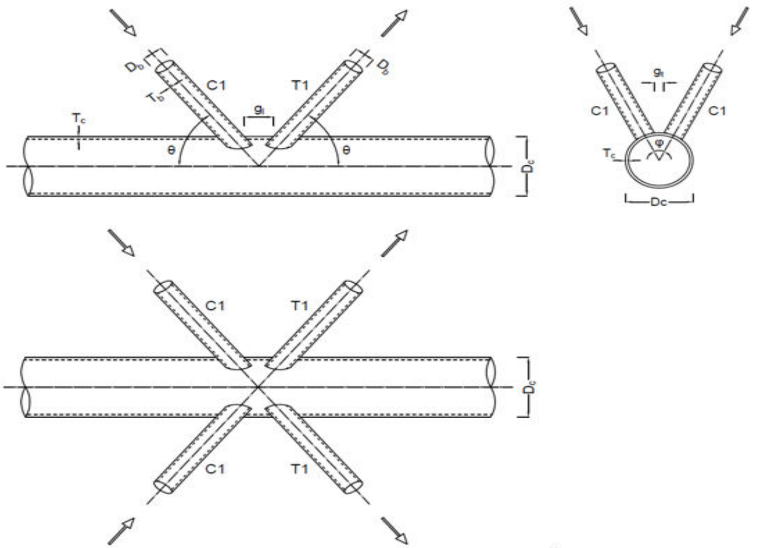


Fig-1. Geometric parameters of multiplanar KK joint

Modelling

In recent years, finite element simulations have become increasingly popular with advances in computer technology and numerical methods. As a result, numerical methods are suitable for specific simulation processes such as material forming operations, rolling and complex geometric shapes, because they are precise and in addition reduce the computational time. ANSYS is a finite element finite element software that is programmed on a finite element method and for a wide range of simulations ranges from simple linear problems to complex nonlinear problems. In this paper, Standard / ANSYS is used for the simulation model. This numerical study included three-dimensional nonlinear finite element analysis with a parametric study to investigate the effect of geometric parameters on the behavior of KK joints.

Numerical Simulation

The results of the numerical simulation affect by the length of the members. To prevent buckling in the brace, the length of the brace was selected to be 200 mm. The length of the chord was selected as 2000 mm to minimize the difference between the normal forces in the compression and tension braces, which could be different due to the rotation of the joint caused by connection eccentricities. The boundary conditions are presented in Figure-3. All connections are subjected to only axial loads, without exerting any kind of bending moments. The compression forces are exerted on the two left braces and the tension forces are exerted on the right braces. The left edge of the chord is attached to the simple support (at the same side of the compression braces) and for the edge of the right side of the chord is attached to a pinned support. The axis directions are depicted that the Y axis is in the upward vertical direction and the Z axis is aligned to the chord in the right direction. A displacement constraint in the Y direction of all nodes is carried out to form a simple support. However, the pinned support is simulated as a displacement constraint for all nodes in the Y and Z directions at the right end of the chord.

The shell element type SHELL181 was used. During the optimization of the mesh development a uniform refinement 5 mm elements was used as shown in Figure-4.

Material properties

The value of elastic modulus and Poisson's ratio are 210000 Mega Pascal and 0.3 respectively. According to EN 10025 a high-yield steel ($\sigma y = 355$MPa and $\sigma u = 510$ MPa) of Steel is commonly used in the offshore industry. The engineering stress–strain material curve was used for both K and multiplanar KK joints. A multilinear isotropic hardening (MISO) material was carried out in Ansys as shown in Figure-2.

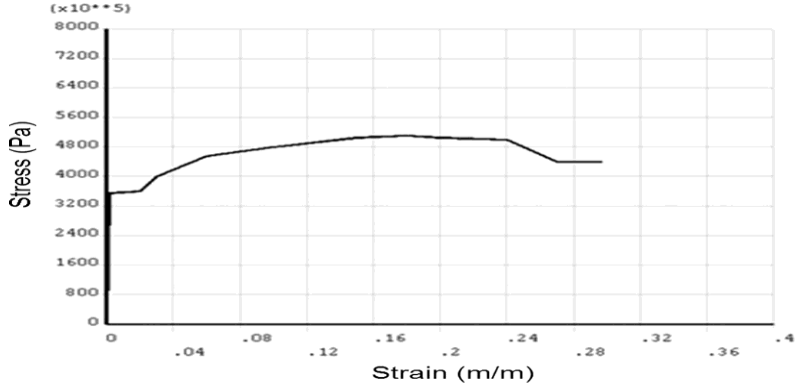


Fig-2 Stress-Strain material curve

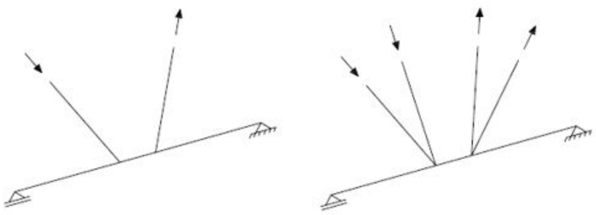


Fig 3. Boundary conditions adopted for K and KK connections

Geometric Parameters

The geometric parameters of multiplanar KK connections presented in Figure-1 usually have some limits for application. According to the Eurocode 3 (2005), the joint has to be designed to follow:

- $30^o \leq \theta \leq 60^o$ (angle in-plane between brace and chord);
- $\gamma = \frac{d}{2t} \leq 25$ and $0.2 < \frac{d}{d} \leq 1.0$, where db is the brace diameter, tb is its thickness and dc is the chord diameter;
- $10 \leq 2\gamma = \quad \leq 50$, where dc is the chord diameter, tc is its thickness;
- g = t1 + t2, where g stands for the longitudinal gap and t1 and t2 are the brace thickness;
- $60^o \leq \varphi \leq 90^o$ (angle between planes in KK connections).

Validation of the numerical model

The numerical model was validated by comparing the output of the finite element model to the numerical results of Wilmshurst and Lee [7], who validates their simulations with experimental tests. The comparison is presented in Table 1, where the connection resistance of 15 KK connections are compared when calculated using the numerical model developed in this work and the results presented in [7]. The results correlated well except in the case of connection with smaller longitudinal and transverse gaps between the braces, namely connection SKK-12. The deviation in the results may be because the numerical model of Lee and Wilmshurst [7] included a simulated weld that was omitted in the present work. The presence of the weld in the model results in a smaller net distance between the braces, and the relative reduction in the distance is greater for connections with smaller longitudinal gaps (≤25 mm). Therefore, the parametric study was restricted to connections with longitudinal gaps greater than 25 mm. It was also observed during the validation that when the parameter β (the brace diameter d divided by the chord diameter d0) was less than 0.2 ($\beta = ¼ \frac{d}{d} \leq 0; 2$), the absence of a weld in the model played an important role. Consequently, the parametric study is restricted to connections with values of β greater than 0.2.

Table 1: Validation of the numerical model comparing to Lee and Wilmshurst [7]

Connection ID	d_i (mm)	g_l (mm)	φ_t	g_t (mm)	β	β′	ζ_t	Ref F(kN)	This Pu(kN)	Work Difference (%)
SKK-01	28.8	18	60	33.4	0.24	0.69	0.28	108.8	109.2	-0.4
SKK-02	28.8	28	60	33.4	0.24	0.69	0.28	103.6	101.9	1.6
SKK-03	28.8	38	60	33.4	0.24	0.69	0.28	99.9	101.1	-1.2
SKK-04	28.8	48	60	33.4	0.24	0.69	0.28	99.4	100.3	-0.9

SKK-05	28.8	58	60	33.4	0.24	0.69	0.28	99.4	101	-1.6
SKK-06	28.8	68	60	33.4	0.24	0.69	0.28	99.1	99.7	-0.6
SKK-07	38.4	18	60	23.6	0.32	0.75	0.2	137.9	137	0.7
SKK-08	38.4	28	60	23.6	0.32	0.75	0.2	126.3	129	-2.1
SKK-09	38.4	38	60	23.6	0.32	0.75	0.2	120.1	126	-4.9
SKK-10	38.4	48	60	23.6	0.32	0.75	0.2	118.5	125.7	-6.1
SKK-11	38.4	58	60	23.6	0.32	0.75	0.2	118	124	-5.1
SKK-12	48.0	18	60	13.4	0.4	0.81	0.11	159	145	8.8
SKK-13	48.0	28	60	13.4	0.4	0.81	0.11	143.5	135	5.9
SKK-14	48.0	38	60	13.4	0.4	0.81	0.11	135.4	131.2	3.1
SKK-15	48.0	48	60	13.4	0.4	0.81	0.11	132.9	129.7	2.4

Parametric study

The main aim of this work is a parametric study for analyzing and comparing the results of the ultimate loading, which the KK and K connections can resist.The connection resistance of 96 KK connections was compared with their corresponding K connections and presented together with geometric data and test results, with the aim of correlating the connection resistance of a KK connection with its corresponding K connection. The results are compiled in graphical form to help identify the connection parameters with the greatest influence on the correlation.

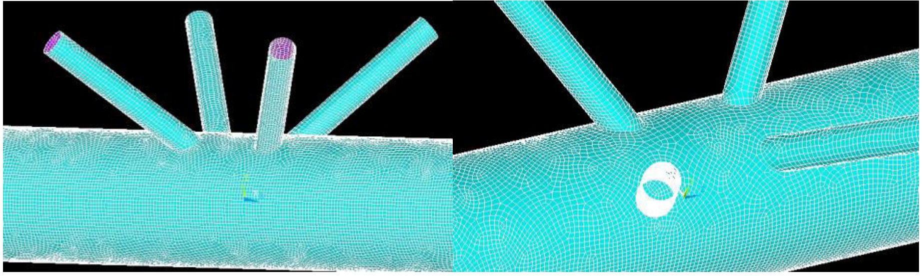
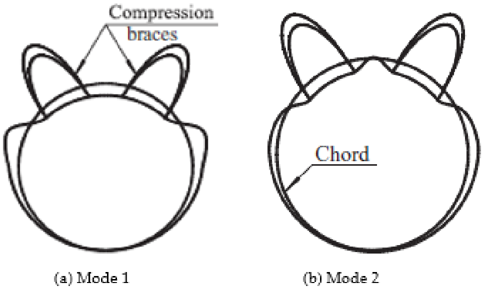


Fig-4 Mesh generation. Uniform refinement and geometric progression of element size for all members

Objective criteria

All previous researches focus to define the failure mode based on mode 1 and 2 as shown in Figure-5But the aim of this research is to predict the ultimate resistance of KK connection from the parameters data or from their corresponding K connection, results from the modeled 96 KK and K connections were analyzed and compared to predict graphs that can present relations between the two types of connections or the relation between the correlation factor and each one of the parameters



(a) Mode 1 (b) Mode 2

Fig 5. Diametric deformation of the chord: a) Horizontal deformation (failure mode 1) and b) Vertical deformation (failure mode 2)

Parametric study data

The simulated connections were chosen to include only chord-wall yielding failure, avoiding brace failure. The numerical model does not consider the weld; therefore, this may cause a little inaccuracy in the results of the finite element model, which can be neglected compared to models with defined weld. In addition, the simulated connections were chosen with the big variety of variables to be sure that the most accurate conclusion could be developed. All model's geometric data are in the following range:

- $35^o \leq \theta \leq 75^o$ (angle in-plane between brace and chord, identical for the compression and tension braces);
- $Db/2Tb \leq 25$ and $0.15 < Db/Dc \leq 1.0$, where Db is the brace diameter, Tb is its thickness and Dc is the chord diameter;
- $gl \geq 2$ Tb, $gl \geq 25$mm, where gl stands for the longitudinal gap and Tb is the braces thickness adopted as equal in the simulations of this work;
- 50 mm $\leq gt \leq$ 95 mm, where gt stands for the transverse gap between braces;
- $\gamma = Dc/2Tc \leq 35$, where Dc is the chord diameter and Tc its thickness;
- $\tau = Tb/Tc$ and $0.5 \leq Tb/Tc \leq 1$, where τ is the brace-to-chord thickness ratio, Tb is brace thickness and Tc is are the chord thickness;
- $60^o \leq \varphi \leq 90^o$ (angle between K planes in KK connections).

Some of the simulated connection models were designed with zero transverse eccentricity as it is the most common condition in practice and some additional simulated models were designed with a transverse eccentricity. KK connections are differed by the angle φ and θ in order to have a big variety of connection cases therefore not all planes got the same corresponding K connection.

The 96 connections were divided into four groups. Each group consists of 24 KK connection models, the only difference between the four groups is the angle between K planes in KK connections 'φ' value.

For Group 1 there are a fixed parameter values which are (Chord diameter Dc= 200 mm , Brace diameter Db= 40 mm, angle in-plane between brace and chord θ= 60º , angle between K planes in KK connections φ= 60º, longitudinal gap gl= 69.28 mm, and the same material data) But with variable parameter values which are (Brace thickness Tb, Chord thickness Tc and transverse gap gt), as shown in Table 2.

Table 2: Details of series 1 connections (Dc=200mm, Db=40mm, θ=60º, gl= 69.28mm, ϕt=60º)

Connection ID	Tb (mm)	Tc (mm)	gt (mm)	τ=Tb/Tc	ɣ=Dc/2tc	ζt=gt/Dc
KK_01	3	3	50	1.00	33.33	0.25
KK_02	3	3	65	1.00	33.33	0.33
KK_03	3	3	80	1.00	33.33	0.40
KK_04	3	3	95	1.00	33.33	0.48
KK_05	3	4	50	0.75	25.00	0.25
KK_06	3	4	65	0.75	25.00	0.33
KK_07	3	4	80	0.75	25.00	0.40
KK_08	3	4	95	0.75	25.00	0.48
KK_09	4	5	50	0.80	20.00	0.25
KK_10	4	5	65	0.80	20.00	0.33
KK_11	4	5	80	0.80	20.00	0.40
KK_12	4	5	95	0.80	20.00	0.48
KK_13	4	6	50	0.67	16.67	0.25
KK_14	4	6	65	0.67	16.67	0.33
KK_15	4	6	80	0.67	16.67	0.40
KK_16	4	6	95	0.67	16.67	0.48
KK_17	4	7	50	0.57	14.29	0.25
KK_18	4	7	65	0.57	14.29	0.33
KK_19	4	7	80	0.57	14.29	0.40
KK_20	4	7	95	0.57	14.29	0.48
KK_21	4	8	50	0.50	12.50	0.25
KK_22	4	8	65	0.50	12.50	0.33
KK_23	4	8	80	0.50	12.50	0.40
KK_24	4	8	95	0.50	12.50	0.48

For Group 2 there are a fixed parameter values which are (Chord diameter Dc= 200 mm , Brace diameter Db= 40 mm, angle in-plane between brace and chord θ= 60º , angle between K planes in KK connections φ= 70º, longitudinal gap gl= 69.28 mm, and the same material data) But with variable parameter values which are (Brace thickness Tb, Chord thickness Tc and transverse gap gt), as shown in Table 3.

Table 3: Details of series 1 connections (Dc=200mm, Db=40mm, θ=60º, gl= 69.28mm, ϕt=70º)

Connection ID	Tb (mm)	Tc (mm)	gt (mm)	τ=Tb/Tc	ɣ=Dc/2tc	ζt=gt/Dc
KK-25	3	3	50	1.00	33.33	0.25
KK-26	3	3	65	1.00	33.33	0.33
KK-27	3	3	80	1.00	33.33	0.40
KK-28	3	3	95	1.00	33.33	0.48
KK-29	3	4	50	0.75	25.00	0.25
KK-30	3	4	65	0.75	25.00	0.33
KK-31	3	4	80	0.75	25.00	0.40
KK-32	3	4	95	0.75	25.00	0.48
KK-33	4	5	50	0.80	20.00	0.25
KK-34	4	5	65	0.80	20.00	0.33
KK-35	4	5	80	0.80	20.00	0.40
KK-36	4	5	95	0.80	20.00	0.48
KK-37	4	6	50	0.67	16.67	0.25

KK-38	4	6	65	0.67	16.67	0.33
KK-39	4	6	80	0.67	16.67	0.40
KK-40	4	6	95	0.67	16.67	0.48
KK-41	4	7	50	0.57	14.29	0.25
KK-42	4	7	65	0.57	14.29	0.33
KK-43	4	7	80	0.57	14.29	0.40
KK-44	4	7	95	0.57	14.29	0.48
KK-45	4	8	50	0.50	12.50	0.25
KK-46	4	8	65	0.50	12.50	0.33
KK-47	4	8	80	0.50	12.50	0.40
KK-48	4	8	95	0.50	12.50	0.48

For Group 3 there are a fixed parameter values which are (Chord diameter Dc= 200 mm , Brace diameter Db= 40 mm, angle in-plane between brace and chord $\theta = 60^{o}$, angle between K planes in KK connections $\varphi = 80^{o}$, longitudinal gap gl= 69.28 mm, and the same material data) But with variable parameter values which are (Brace thickness Tb, Chord thickness Tc and transverse gap gt), as shown in Table 4.

Table 4: Details of series 1 connections (Dc=200mm, Db=40mm, $\theta=60^{o}$, gl= 69.28mm, $\phi t=80^{o}$)

Connection ID	**Tb (mm)**	**Tc (mm)**	**gt (mm)**	**τ=Tb/Tc**	**ɣ=Dc/2tc**	**ζt=gt/Dc**
KK-49	3	3	50	1.00	33.33	0.25
KK-50	3	3	65	1.00	33.33	0.33
KK-51	3	3	80	1.00	33.33	0.40
KK-52	3	3	95	1.00	33.33	0.48
KK-53	3	4	50	0.75	25.00	0.25
KK-54	3	4	65	0.75	25.00	0.33
KK-55	3	4	80	0.75	25.00	0.40
KK-56	3	4	95	0.75	25.00	0.48
KK-57	4	5	50	0.80	20.00	0.25
KK-58	4	5	65	0.80	20.00	0.33
KK-59	4	5	80	0.80	20.00	0.40
KK-60	4	5	95	0.80	20.00	0.48
KK-61	4	6	50	0.67	16.67	0.25
KK-62	4	6	65	0.67	16.67	0.33
KK-63	4	6	80	0.67	16.67	0.40
KK-64	4	6	95	0.67	16.67	0.48
KK-65	4	7	50	0.57	14.29	0.25
KK-66	4	7	65	0.57	14.29	0.33
KK-67	4	7	80	0.57	14.29	0.40
KK-68	4	7	95	0.57	14.29	0.48
KK-69	4	8	50	0.50	12.50	0.25
KK-70	4	8	65	0.50	12.50	0.33
KK-71	4	8	80	0.50	12.50	0.40
KK-72	4	8	95	0.50	12.50	0.48

For Group 4 there are a fixed parameter values which are (Chord diameter Dc= 200 mm , Brace diameter Db= 40 mm, angle in-plane between brace and chord $\theta = 60^{o}$, angle between K planes in KK connections $\varphi = 90^{o}$, longitudinal gap gl= 69.28 mm, and the same material data) But with variable parameter values which are (Brace thickness Tb, Chord thickness Tc and transverse gap gt), as shown in Table 5.

Table 5: Details of series 1 connections (Dc=200mm, Db=40mm, $\theta=60^{o}$, gl= 69.28mm, $\phi t=90^{o}$)

Connection ID	**Tb (mm)**	**Tc (mm)**	**gt (mm)**	**τ=Tb/Tc**	**ɣ=Dc/2tc**	**ζt=gt/Dc**
KK-73	3	3	50	1.00	33.33	0.25
KK-74	3	3	65	1.00	33.33	0.33
KK-75	3	3	80	1.00	33.33	0.40
KK-76	3	3	95	1.00	33.33	0.48
KK-77	3	4	50	0.75	25.00	0.25
KK-78	3	4	65	0.75	25.00	0.33
KK-79	3	4	80	0.75	25.00	0.40
KK-80	3	4	95	0.75	25.00	0.48
KK-81	4	5	50	0.80	20.00	0.25

KK-82	4	5	65	0.80	20.00	0.33
KK-83	4	5	80	0.80	20.00	0.40
KK-84	4	5	95	0.80	20.00	0.48
KK-85	4	6	50	0.67	16.67	0.25
KK-86	4	6	65	0.67	16.67	0.33
KK-87	4	6	80	0.67	16.67	0.40
KK-88	4	6	95	0.67	16.67	0.48
KK-89	4	7	50	0.57	14.29	0.25
KK-90	4	7	65	0.57	14.29	0.33
KK-91	4	7	80	0.57	14.29	0.40
KK-92	4	7	95	0.57	14.29	0.48
KK-93	4	8	50	0.50	12.50	0.25
KK-94	4	8	65	0.50	12.50	0.33
KK-95	4	8	80	0.50	12.50	0.40
KK-96	4	8	95	0.50	12.50	0.48

Analysis of results

In order to figure out the outline structure of the proposed 96 joints were analyzed to investigate the effect of the various geometric parameters on correlation factor (Pu′=KK Pu/ K Pu) as follows:

Table 6: Details of geometric parameters on correlation factor

Connection ID	KK Pu (KN)	K Pu (KN)	-- –	Connection ID	KK Pu (KN)	K Pu (KN)	--–
KK_01	36.5	35.4	1.03	KK-25	33.5	34.7	0.97
KK_02	31.9	32.5	0.98	KK-26	33.5	33.2	1.01
KK_03	30.5	32.6	0.94	KK-27	33.7	33.5	1.01
KK_04	32.8	32.7	1.00	KK-28	34.3	34.9	0.98
KK_05	64.3	55.2	1.16	KK-29	61.3	58	1.06
KK_06	59.2	57.5	1.03	KK-30	58.8	58.2	1.01
KK_07	57.7	57.2	1.01	KK-31	58.2	57.4	1.01
KK_08	57	56.8	1.00	KK-32	57.9	57.5	1.01
KK_09	100.3	92.9	1.08	KK-33	95.6	89.9	1.06
KK_10	91.9	90.8	1.01	KK-34	91.2	88.3	1.03
KK_11	88.9	89.9	0.99	KK-35	89	89	1.00
KK_12	87	89.3	0.97	KK-36	88.6	89.4	0.99
KK_13	139.4	127.5	1.09	KK-37	134.4	123.3	1.09
KK_14	129.6	124.8	1.04	KK-38	125.6	121.5	1.03
KK_15	123.3	123.5	1.00	KK-39	123.1	122.3	1.01
KK_16	120.2	122	0.99	KK-40	122.1	122.9	0.99
KK_17	179.7	164.9	1.09	KK-41	171.3	160.6	1.07
KK_18	167.9	161.8	1.04	KK-42	162.7	158.1	1.03
KK_19	159.8	158.7	1.01	KK-43	158.9	157.7	1.01
KK_20	155.4	158.4	0.98	KK-44	157.5	158.7	0.99
KK_21	219.8	203.3	1.08	KK-45	210.7	196.1	1.07
KK_22	206.6	198.7	1.04	KK-46	201.2	194.4	1.03
KK_23	197.7	195.7	1.01	KK-47	196.5	194.5	1.01
KK_24	192	194.3	0.99	KK-48	193.9	195.3	0.99

Table 7: Details of geometric parameters on correlation factor

Connection ID	KK Pu (KN)	K Pu (KN)	-- –	Connection ID	KK Pu (KN)	K Pu (KN)	--–
KK-49	36.1	33.9	1.06	KK-73	36.5	35.4	1.03
KK-50	33.3	33	1.01	KK-74	31.9	32.5	0.98
KK-51	33.3	32.7	1.02	KK-75	30.5	32.6	0.94
KK-52	33.8	33.7	1.00	KK-76	32.8	32.7	1.00
KK-53	62.4	58.6	1.06	KK-77	64.3	55.2	1.16
KK-54	58.5	57.5	1.02	KK-78	59.2	57.5	1.03
KK-55	57.8	57.9	1.00	KK-79	57.7	57.2	1.01
KK-56	57.3	57.2	1.00	KK-80	57	56.8	1.00
KK-57	98	91.3	1.07	KK-81	100.3	92.9	1.08

KK-58	91.3	89.1	1.02	KK-82	91.9	90.8	1.01
KK-59	88.3	88	1.00	KK-83	88.9	89.9	0.99
KK-60	87.8	88.9	0.99	KK-84	87	89.3	0.97
KK-61	136.2	125.1	1.09	KK-85	139.4	127.5	1.09
KK-62	126.9	122.4	1.04	KK-86	129.6	124.8	1.04
KK-63	122.1	121.1	1.01	KK-87	123.3	123.5	1.00
KK-64	120.7	122	0.99	KK-88	120.2	122	0.99
KK-65	175.8	163.2	1.08	KK-89	179.7	164.9	1.09
KK-66	163.9	159.5	1.03	KK-90	167.9	161.8	1.04
KK-67	158.2	156.8	1.01	KK-91	159.8	158.7	1.01
KK-68	155.8	158.9	0.98	KK-92	155.4	158.4	0.98
KK-69	214.7	199.1	1.08	KK-93	219.8	203.3	1.08
KK-70	202.5	196	1.03	KK-94	206.6	198.7	1.04
KK-71	196	193.8	1.01	KK-95	197.7	195.7	1.01
KK-72	192.8	194.2	0.99	KK-96	192	194.3	0.99

The results were classified according to the transversal gap (gt) as show in Figure-6. As mentioned before the transverse gap (gt) parameter got four different values in this parametric study gt= 50 ,65, 80, 95 from each group results an equation has been developed to predict the ultimate capacity of the multiplanar KK-joints from the uniplanar K-joints by using a fixed correlation factor for each value as follow:

- *For gt = 50*
- *Pu (KK) = 1.0766 Pu (K) (KN)*
- *For gt = 65*
- *Pu (KK) = 1.0322 Pu (K) (KN)*
- *For gt = 80*
- *Pu (KK) = 1.0077 Pu (K) (KN)*
- *For gt = 95*
- *Pu (KK) = 0.9904 Pu (K) (KN)*

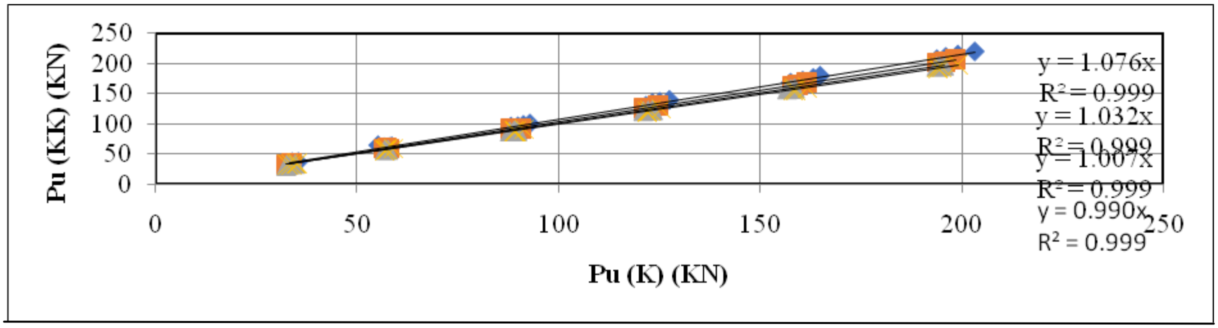


Fig 6 . Pu (K)-Pu (KK) relation according to the (gt)

The correlation factor developed for the four-transverse gap (gt=50, 65, 80, 95) were analyzed to figure out the relation between the four values which is presented in Figure-7 and a new equation is developed, which can estimate the correlation factor depending of the transverse gap (gt) parameter. The general structure of the proposed formula for these correlations is:

- correlation factor = $1.7841(gt)^{-13}$

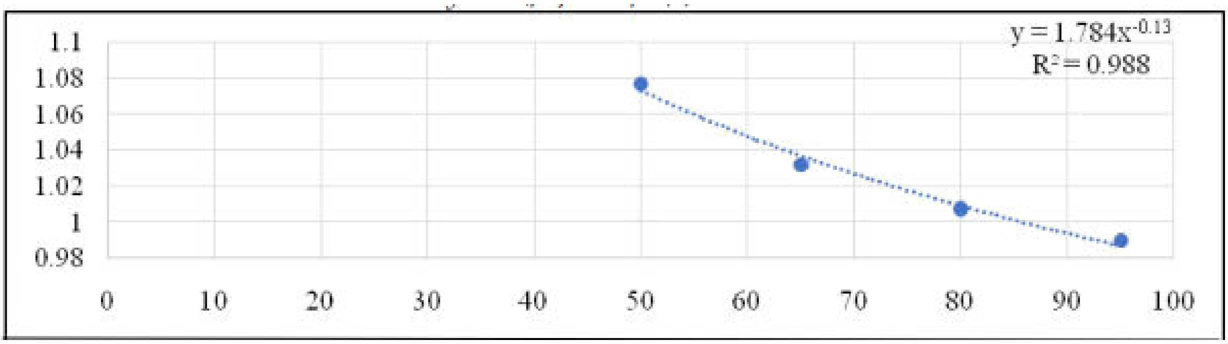


Fig 7. Correlation Factor- Transverse Gap (gt) Curve

Conclusion

The design of multiplanar tubular connections traditionally follows guidelines derived from the interpretation of results on strength testing of planar joints. The normal practice adopted is to treat each plane in isolation and design with no reference to the effect of the presence of loads in the out of plane braces. The standard practice is to treat every plane separately and then multiply the resistance by a unique correlation coefficient that is not depend on the joint geometry. This study was held using a well-calibrated and validated finite-element model, the joints were designed with longitudinal and transversal gap region between the diagonal braces and the connections were subjected to symmetrical axial loading. Analyses were performed using the finite element program (ANSYS APDL). In all, 96 joints were analyzed to investigate the effect of the various geometric parameters on correlation factor (Pu′=KK Pu/ K Pu). This numerical study included three-dimensional nonlinear finite element analysis with a parametric study to investigate the effect of geometric parameters on the behavior of KK joints. The 96 connections were divided into four groups. Each group consists of 24 KK connection models, the only difference between the four groups is the angle between K planes in KK connections ‘φ’ value. The results are compiled in graphical form to help identify the connection parameters with the greatest influence on the correlation.

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