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"Research Note"

NUMERICAL STUDY ON SEISMIC BEHAVIOUR OF PRECAST CONCRETE CONNECTION ZONE*

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Abstract– Precast industrial plants in Turkey experienced considerable damage during the recent earthquakes in Turkey. The presented paper is based on a parametric study to evaluate the seismic performance of a code-designed moment-transferring scarfed connection that is widely utilized in precast industrial buildings in Turkey. Firstly, the seismic behavior of a typical symmetrically pitched double-bay precast framed system with a scarfed beam to the column connections was investigated. The coefficient of elastic rotational stiffness, R_θ, and maximum stress values were then obtained by finite element idealization with an approach of a repeated analysis. Finally, a parametric study was carried out for different values of R_θ in order to evaluate the effect of joint elasticity on the behavior of a precast frame under seismic action.

Keywords– Prefabricated systems, precast frame system, connection zone, semi-rigid connection, elastic rotational stiffness, seismic performance

1. INTRODUCTION

Precast concrete industrial systems experienced considerable damage during the 1998 Adana-Ceyhan and 1999 Marmara earthquakes in Turkey [1-2]. Most of the prefabricated structures in those areas are single story multi-bay systems with light metal roof decking. The field investigations and analytical evaluations revealed that a high percentage of such structures, unfortunately, were not designed or built with satisfactory earthquake safety standards. The majority of the poor performance was due to inadequate lateral stiffness, inadequate shear capacity, a low degree of structural system indeterminacy, the lack of diaphragm action, missing quality control and detailing errors at the connection zones.

The presented paper is a research study to evaluate the seismic performance of a moment-transferring scarfed connection of precast industrial buildings widely utilized in Balkan countries and in Turkey. The numerical approach is given for determining the elastic rotational stiffness, R_θ, of the considered connection and the maximum stress values under vertical and seismic loading cases.

2. SCARFED JOINT OF A PREFABRICATED INDUSTRIAL PLANT

Precast concrete industrial buildings and warehouses are usually selected as multi-bay single-story frames and symmetrically pitched portal frames called "Lambda Frame" are widely used for industrial plants and warehouses. Long spanned beams cast in one length would present problems both in transport and the erection phase; therefore, *scarfed joints* as shown in Fig.1, are usually provided. The rafters are usually broken at one of the contra flexure points at the span length, and these two segments are then lapped over

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each other and joined by two bolts to more conveniently form these connections. These bolts provide the shear resistance as well as transferring the axial thrust. The connection zone may be concreted later on to provide monolithic behavior.

Fig. 1. Scarfed joint of a prefabricated industrial plant

Since these connection zones are the weakest parts of the structures, connection details require careful consideration. During the analysis procedure, these types of ridge connections are generally classified as moment transferring joints. However, the consideration of an elastic rotational stiffness at this type of joint will be more realistic, because the degree of fixity of the considered zone might be reduced to a certain extent with the use of bolts.

3. NUMERICAL INVESTIGATION

A typical Lambda frame of 40.00m×36.00m in plan, which is very common in industrial buildings in the Marmara region of Turkey, was selected. The prefabricated system is composed of seven symmetrical two-bay precast concrete frames with 20.00m span lengths in the main direction, as illustrated in Fig. 2. The columns, 6.00m in height, are assumed as rigidly connected to the single socket footings, which are cross-tied with grave beams, thus the rotations were neglected.

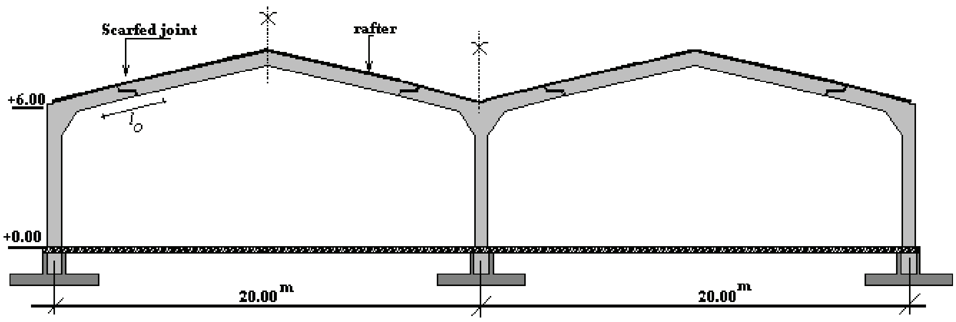

Fig. 2. The principal section of the two-bay primary frame

The described structure is one of the existing industrial buildings located at the first-degree earthquake zone (A_0=0.40g) in the Marmara region where a serious earthquake is expected in the near future. The soil profile is Z4 type with spectrum characteristic periods T_A = 0.20sec and T_B =0.90sec of the soil [3]. The distributed live loads including the snow load are taken as q_l=10.58 kN/m. The material properties are concrete and the steel classes are C30, S420, respectively.

Scarfed joints of the precast system were produced by overlapping the segments of the rafter (part II) and the ridge (part I) at about the contra-flexure points on each side of the roof girders as shown in Fig. 3. The connection zone was fastened by two ϕ26 high-strength bolts, located through the cylindrical holes of a 30mm diameter to be made during the production phase.

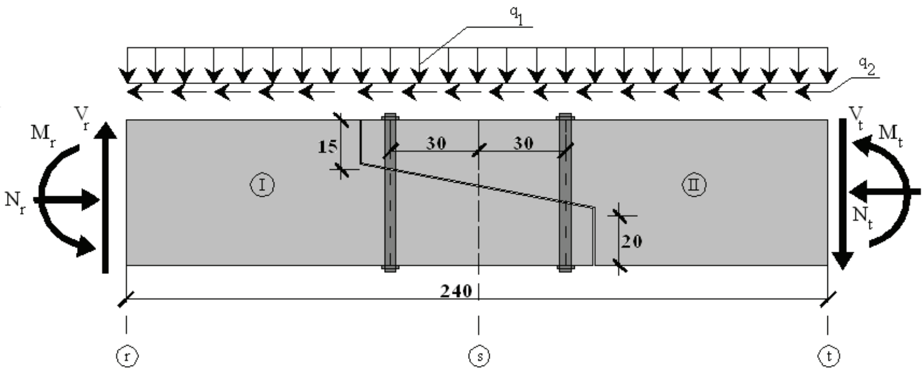

Fig. 3. The investigated scarfed connection

In order to evaluate the behavior of the scarfed joints under earthquake loading, the connection zone, 2.40m in length, was modelled by finite element idealization, as shown in Fig. 4 and analyzed with the SAP2000 Structural Analysis Package [4]. The mathematical model was formed by 0.05x0.05 m sized 480 plane-stress rectangular finite elements and was solved as planar shell members, with two degrees of freedom at nodal points.

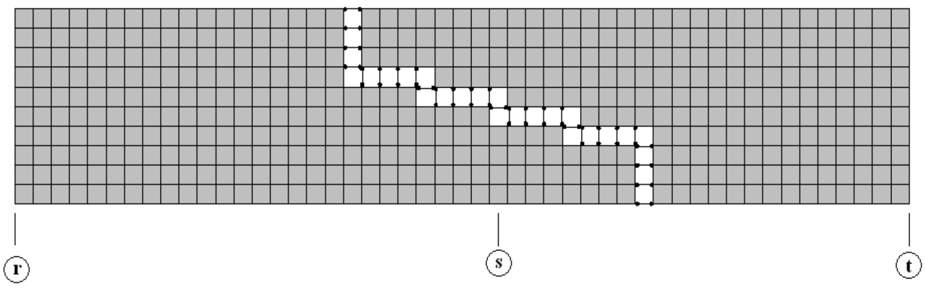

Fig. 4. Finite element idealization of 2.40m long connection zone

27 fictitious bars that resist only axial forces were placed 0.05 m distances apart, between the two segments of the joint along the connection line in order to examine the internal forces and relative displacements of each segment. The analysis was performed under combined loading to obtain the critical internal forces. The repeated analysis explained in Gulay and Arslan [5] was performed to determine the stress distribution for checking the adequacy of the connection zone.

As to determine the relative rotation of the two overlapping segments I and II at the scarfed joint, first, the finite element analysis was carried out, due to the unit end moments (1.00 kNm) at the cross-sections of *r* and *t*, assuming a monolithic connection region. The relative rotation of $\theta'_A = 0.162\text{x}10^{-4}$ radians was obtained. Then, the analysis was repeated under the unit end moments at *r* and *t* using the contact surface with 7 bars, as shown in Fig. 5. The rotation of $\theta_A = 0.433\text{x}10^{-4}$ radians was obtained by dividing the relative difference of the displacements of the top and bottom fibers by d = 0.50m of the cross-sectional height. Thus, the additional rotation $\Delta\theta$ due to the elastic connection of the scarfed joint was computed by

$$\theta_A - \theta'_A = \Delta\theta \tag{1}$$

So, the rotational stiffness R_θ of the prefabricated joint would be the inverse of this value as follows:

$$R_\theta = \frac{1}{\Delta\theta} = 36900 \text{ kNm /rad.} \tag{2}$$

When the analysis of the designed two-bay frame was repeated by assuming semi-rigid connections at the scarfed joints, by using the calculated numerical value of R_θ= 36900 kNm/rad for the rotational stiffness, the bending moment at the section *s* is reduced 12% due to its distribution towards the other ends of the members.

A parametric study was also carried out to examine the effect of different values of R_θ on the lateral displacements δ_x and the bending moments produced at critical cross-sections *a, b, c, d, e* and *g* of the prefabricated frame, indicated in Fig. 5 and Table 1.

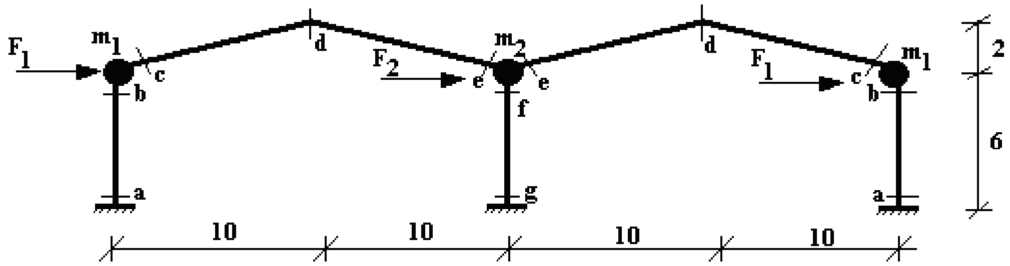

Fig. 5. Idealized model of the primary frame

Table 1. Roof displacements δ_x and the bending moments at *a, b, s, d, e* and *g* of the main frame for different R_θ values under combined loading

R_θx 10^4(kNm/rad)	δ_x (m)	M_a (kNm)	M_b (kNm)	M_s (kNm)	M_d (kNm)	M_e (kNm)	M_g (kNm)
0.00	0.049	119.791	-131.884	0.000	58.101	-133.295	-0.114
0.50	0.041	113.492	-125.980	9.928	65.779	-127.454	-0.875
1.00	0.032	107.324	-118.207	15.213	73.211	-121.213	-0.913
1.50	0.030	103.981	-110.575	26.598	84.745	-112.454	-1.009
2.00	0.027	100.105	-106.913	30.913	89.311	-108.711	-1.312
2.50	0.016	99.390	-104.889	33.560	91.716	-106.310	-1.545
3.00	0.015	98.311	-103.451	34.751	93.333	-104.552	-0.711
3.69	0.014	96.312	-99.101	36.310	95.875	-100.671	-1.154
4.00	0.014	93.761	-98.764	36.700	96.005	-100.306	-1.231
4.50	0.014	89.101	-94.215	36.913	96.315	-96.707	-1.001
5.00	0.014	87.254	-92.670	37.101	97.341	-95.301	-1.145
Rigid(∞)	0.013	82.774	-90.405	41.301	108.13	-93.405	-1.771

4. RESULTS AND DISCUSSION

The value of the rotational stiffness R_θ was computed numerically and a parametric study was carried out for different values of R_θ. The roof displacement values could be decreased by 72% as the value of R_θ is changed from zero to infinity, that is, the connection changed from hinged to monolithic, but still they are all below the code level, whereas the computed displacements in the longitudinal direction may exceed the code limits, depending upon the support conditions of purlins, which are considered the main reason for experiencing failures during past earthquakes.

On the other hand, the bending moments are decreased by 70 % at cross-sections *a* and, *e* and increased by about 86 % at section *d* as the degree of rotational elasticity is increased. The increase in bending moments can be compensated with additional reinforcements at critical sections, while the excess of displacements will cause an overturn of the structure.

The finite element analysis of the connection zone proved that the seismic code provisions in Turkey are sufficient in terms of stresses for the most unfavorable combined loading case, whereas the displacements may exceed the limit values depending upon the support conditions in both directions. Moreover, the constructional details must be done properly at the site, since displacements as well as internal force distributions might change considerably with the increase in the inelasticity at the connection zones, and the degree of fixity of the zone might be reduced to a certain extent, even with the use of high-strength bolts. Thus, it is also more convenient to consider the connections as rotationally elastic joints in the analysis procedure.

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