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REVIEW OF PREVIOUS PAPERS ON ANALYSIS OF COLD FORMED STEEL RACK STRUCTURE

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Abstract – *In this paper, recent developments in technology and application in design and analysis of cold formed steel rack structure are outlined and this is followed by more detailed consideration of the related design procedures. And discuss about the previous studies carried out on cold formed steel rack structure. The studies include several modes of analysis like pushover analysis, finite element analysis, shake table tests, Seismic analysis (time history analysis and response spectrum analysis), dynamic analysis, Non-linear analysis, Dynamic analysis, Applied Element Method (AEM), and Component Method. This paper also deals with the cause of failure of racks. This paper is a review paper of old study. For study of this paper several papers were analyse for different loading conditions and different types of analysis.*

Key Words: cold formed steel rack, pallet rack, pushover analysis, Seismic analysis, Dynamic analysis.

1. INTRODUCTION

Steel storage pallet racks are used worldwide for storage of palletized goods and popular for their ease of customization, construction, and economy [1]. Rack systems are almost like as the framed steelworks basically used for civil and commercial buildings, but great differences in geometry of members and the connection systems. Rack can be failed due to exceeding of applied load limit or seismic load [2]. So, pallet rack system has bracing systems which are mostly placed only in the cross-aisle direction. Therefore, design of pallet racks is quite complex [2]. Industrial pallet rack systems are mainly made up of three-dimensional structural arrangement using cold-formed steel members [3]. Several studies were carried out on cold formed steel racks for its stability, durability, stiffness, load bearing capacity and earthquake resistance capacity. This paper deals with such type of papers. Pallet racks are specially designed for the storage of goods in warehouse across the world. The analysis of pallet racks is carried out by pushover analysis, seismic analysis, finite element methods, dynamic analysis, etc.

Pushover Analysis is a static, nonlinear procedure in which the magnitude of the structural loading is enhanced increased as per certain predefined pattern. In effect, the structure is pushed sideways well into the inelastic range till total failure or collapse occurs [4]. A non-linear analysis was undertaken using the multi-linear stiffness value method. The analysis was continued until one of the joints yielded at which the analysis was stopped as it was accompanied by a high sway value [3]. Seismic analysis includes two types of analysis; response spectrum analysis and time history analysis.

For industrial purpose, selective pallet rack is most common type of rack is used and adopted worldwide. This type of rack is arranged as single entry unit (SEU) shown in fig.1(b) and double entry unit (DEU) shown in fig.1(b) [5]. In first case goods are stored in single raw and in second case they are stored back to back [5]. In this paper all the papers are discussed are worked either on SEU or DEU. This SEU and DEU includes bracings for neglect the seismic load, these bracings are generally spine bracing, upright bracing and frame bracing. The spine bracing rack system include uprights, frame bracings, bracing brackets, pallet beams, beam end connectors, plane bracings, spine bracings and bracing beams [6]. The uprights are generally thin walled perforated open section. The steel racks are seeming to be a multi-story building when seen from bottom. Configuration of steel storage rack structures is simple, they are assembled from beams, uprights and bracings, their design and analysis

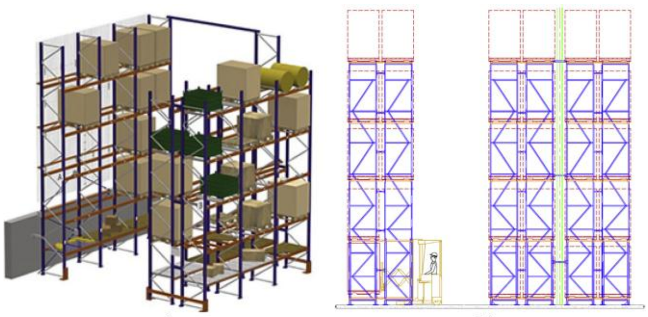

Fig – 1: Selective pallet rack systems: a) single entry; b) double entry.

are complicated. As the nature of cold formed steel elements, their performance is influenced, among others, by local deformations at the uprights and bracing members at the connections [7]. The beam-to-upright semi-rigid connections and base plate-to-floor also influence the structural behaviour of the system. In this study, behaviour of rack structure is studied by analysing the previous studies.

2. LITRECTURE REVIEW

Federico Gusella, Sanjay Raja Arwade, Maurizio Orlando, Kara D. Peterman [1] studied the influence of the structural details and randomness in the geometrical features on the structural response of rack connection and mechanical properties of connection members (beam, weld, connector and column) [1]. They use sensitivity analysis for their study in which they tested a cold formed steel racks joints for beams and upright (columns). They carried out their experiments by two methods; one was experimental test and other was Mechanical model. For experimental test they obtained a moment rotation curve through the test procedure. They applied some load on the beams and increased monotonically until failure. And in Mechanical model basically based on the component method (CM). The CM can be applied to any kind of connection provided that the basic sources of strength and deformation are properly identified and modelled [1]. They organised CM in three phases, first is to identifying the component in connection, contributing to structural response. He second one contains of components of modelling via force-displacement relationship. In third phase components are assumed to have infinite ductility; thus, the rotational capacity of the connection cannot be predicted [1]. They also carried out flexural resistance probabilistic analysis and rotational stiffness probabilistic analysis on the rack connection of probabilistic model [1]. After their experiments and studies, they come on a conclusion that the flexural resistance and initial elastic flexural stiffness of cold formed steel rack connection are affected by the local response of connection component and normal probability distribution function well fits for both the connection ultimate moment and initial flexural stiffness histograms. Also highlight the effect on failure mode and ultimate moment due to varying connection configurations and the flexural stiffness of the rack joint is limited by the connector stiffness, and is thus the most critical feature which should be controlled with greater accuracy in the manufacturing process [1].

K.M. Bajoria and K.K. Sangle [2] done a capacity-based design of cold formed storage rack structures under seismic load for rigid and semi rigid connections [2]. They did non-linear analysis or pushover analysis of cold formed steel rack on Sap2000NL software. For pushover analysis they made two assumption that are fundamental mode of vibration is the predominant response of the structure and Higher mode effects are not considered in the nonlinear static pushover analysis. This paper deals with the study of behaviour of cold-formed steel storage rack structure, with semi rigid and rigid connections, subjected to gravity and seismic load and improvement in the base shear at the time of collapse [2]. In this paper torsionally strengthen sections were used. In this paper pattern of latera load is obtained from seismic forces distribution pattern as IS 1893-2002. The main objective of this paper was to the base shear at the time of collapse and maximum displacement [2]. By studying non linear pushover analysis they conclude that the analysis is useful tool for the pallet racks. They conclude that how we can minimize the twisting effect by improving the base shear and also conclude that it is better to provide upright sections at different heights [2].

M. Abdel-Jaber, R.G. Beale, M.H.R. Godley [3] deals with the Numerical study on semi-rigid racking frames under sway [3]. Their main purpose for carrying out that test was to investigate the free sway behaviour of a racking frame with flexible joints and to study the joint behaviour under the effect of loading and unloading. They theoretically analyse pinned-base pallet rack frames under a combination of point loads normal to the ground and with proportionally increasing side loads [3]. According to their theory side loads produced moment-reversal in the beam-column joints [3]. They compute result on the basis of comparison of experiment taken placed on two bi-linear models. They produced a Moment–rotation curves of connections by the cantilever method that applied in testing the connection. The same joint was tested under hogging and sagging moments both [3]. Results of the experiments showed that moment–rotation curves for these joints are highly non-linear, the curve under the reversed moment follows a different path, unloading curve is elastic and reloading follows the same straight line [3]. In this paper they mentioned that the frames are lifted away from the block so that free sway can occur and due to the looseness of joints frames are rested on the blocks. As the loading was applied the gaps closed and the loading system became purely axial. They also conduct structural analysis for which their main objectives were to establish a simple and practical analysis procedure for the analysis of steel frames with semi-rigid connections. For the purpose of the analysis, a computer program Semi-Rigid Joint Frame Analysis (SRJFA) incorporating the stiffness method was written. The stability function approach was used in modelling the column element. They used a two story, one bay frame with fixed base to validate the program. Numerical investigation of the portal frames includes three different methods of modelling the joint behaviour were used in the analysis; Multi-linear stiffness curve behaviour, Linear stiffness value obtained by the SEMA code, Average stiffness value obtained by the FEM code method [3]. After their experiments, tests and numerical calculations they conclude that the differences between the FEM code and the more accurate model were small and hence the FEM code can be used to predict the behaviour of pallet rack portal frames, even when unloading takes place [3].

Sreedhar Kalavagunta, Sivakumar Naganathan and Kamal Nasharuddin Bin Mustapha [4] did Pushover Analysis for Cold Formed Storage Rack Structures to investigate the progressive collapse of cold formed storage rack structures subjected to seismic loading [4]. The purpose of this paper is to estimate the structural performance by assessing the strength and deformation capacities using static, nonlinear analysis and comparing these capacities with the demands at the corresponding performance levels [4]. In this paper pushover analysis were carried out by two method; Capacity Spectrum Method (CSM) and Displacement Coefficient Method (DCM). In Capacity Spectrum Method The structure capacity is represented by a pushover curve, often termed as capacity curve. This represents the lateral displacement as a function of the force applied to the structure. And Displacement Coefficient Method, provides a numerical process for estimating the displacement demand on the structure, by using a bilinear representation of capacity curve and a series of modification factors, or coefficients, to calculate a target displacement. The design of pallet rack was carried out by STAAD.Pro for its capacity curve. They than compare STAAD.Pro result and manual calculation result. After completing their analysis, they conclude that collapse load of 29.9kN makes rack to displace 10.18 inch [4]. So, the structure can be in elastic limit at 22.07 kN and plastic hinge produce at 29.9 kN [4]. In this paper they also suggest that the alternative of pushover analysis can be time history analysis.

Dan Dubinaa, Ioan Margineana, Florea Dinua [5] deal with the Impact modelling for progressive collapse assessment of selective rack systems [5]. Progressive collapse analysis was done by removing of member(s) or applied alternative loads on same member; they used method which is Numerical modelling using the Applied Element Method (AEM) [5]. This is do so because structure is subjected to several local failure; Overloading or wrong loading pattern, Accidental collision of forklift trucks, Earthquakes and Localized fire. They make structure to collapse and produce their results which are Ultimate resistance under gravity loads of undamaged racks, Notional upright removal and Explicit forklift impact [5]. After gaining all these results they conclude that non linear pushover analysis on undamaged pallet rack showed that the use of top plan bracing is effective in increasing the ultimate load capacity for most cases [5]. And stronger beam-to-upright connections lead to structures with higher load-bearing capacities. For damage scenarios involving corner and penultimate uprights, progressive collapse is prevented, and damage is contained within the area adjacent to the local damage for both static and dynamic analyses [5]. When forklift impact leads to heavy damage or complete loss of an upright, the application of alternate load path method may result in less overall damage compared to explicit impact analysis. In case of middle upright collapse is initiated for all configurations. In this paper they indicate that the forklift-structure interaction during impact is not completely covered by conventional element removal and further developments are necessary.

Lingfeng Yina, Gan Tang, Zhanjie Li, Min Zhang, Bo Feng [6] done Responses of cold-formed steel storage racks with spine bracings using speed-lock connections with bolts by Static elastic-plastic pushover analysis [6]. The objective of this paper is to investigate the seismic performance of cold-formed steel storage racks with spine bracings using a variety of speed-lock connections with bolts, where their connection behaviours were based on previous experimental studies through monotonic and cyclic loading tests [6]. In this paper they analyse single entry units (SEU) and double entry units (DEU) of rack as it is not possible to represent rack as whole because it makes analysis quite complicated. The single-entry unit consist of one unit of rack and double-entry unit consist of two way of racks, they both include spine bracing, upright, frame bracing and spine bracing. The elastic-plastic connection models were developed for several type of joints which are; speed lock connection, speed lock connection with an upper bolt, speed lock connection with a lower bolt, speed lock connection with two bolts and speed lock connection with two bolts and a full flange welding [6]. This all mentioned joints were under applied seismic load and their seismic performance is to be check. The racks (SEU and DEU) were modelled and analysed using the software SAP2000. For the analysis of cold formed rack standard N90, N100 and K100X50 section rack members were used [6]. The structure was analysed for the seismic load by pushover analysis, seismic performance, Plastic hinge distribution and Seismic response modification factor [6]. The result obtained from pushover analysis is that the increasing deformation in the plastic region, the behaviours diverged as well with a sudden loss of stiffness for some types of connections, which may lead to a fragile collapse [6]. Result by seismic performance, the collapse mechanism of the single-entry unit rack started from the bracket bracings from bottom to top while the collapse mechanism of the Double-entry unit rack started from the uprights of the lower spine bracing regions, there is a sudden base shear capacity drop as can be observed from the pushover curves [6]. Result by Plastic hinge distribution, the connection types showed similar impact on the number and damaged stage of plastic hinges as those of the single-entry unit racks. Double-entry unit racks further demonstrated the excellent performance of connection type full flange welding with welds and bolts by reducing the total number of plastic hinges by half. And result obtained by Seismic response modification factor, the major damages of the single-entry unit racks lying in the spine bracing systems other than the upright and beam connections and the major damages of the DEU racks concentrating at the uprights around the connections. Conclusion of this paper is that the impact of the connection types on the response modification factors was great for the double-entry unit racks while small for the single-entry unit racks. Through the whole pushover results, the double-entry unit rack demonstrated better deformability and possessed a higher response modification factor than the single-entry unit rack. The collapse mechanism of the single-entry unit rack started from bracket bracings from bottom to top while the DEU rack started from the uprights near the spine bracings from bottom.

Nima Talebian, Benoit P. Gilbert, Nadia Baldassino, Hassan Karampour [7] done Finite Element Analysis on Steel storage racks or Cold-formed steel for Factors contributing to the transverse shear stiffness of bolted cold-formed steel storage rack upright frames with channel bracing members [7]. They indicate that accurately determining the transverse shear stiffness of steel rack upright frames is essential in calculating the elastic buckling load, performing earthquake design and serviceability checks. In the cross-aisle direction, the stability is ensured by the upright frames, each consisting of two uprights connected by bracing members [7]. The bracing members are commonly cold-formed lipped channel-sections bolted to the upright flanges and welded connections are also encountered. The analysis was done by two methods; Experimental tests used to verify Finite element models in which manual experiments was done on cold formed rack and second was Finite element modelling which capture both the global and local deformations of the upright frames [7]. Results are based on the compare Finite element models with experimental results. Yielding at the bolt holes were found to occur at an early stage of loading (particularly for the frames tested following the alternative AS4084 test set-up) and this is captured by the Finite element modelling. due to large local deformations at the bolt holes, the Finite element modelling stopped converging before reaching the peak load [7]. In this paper the conclusion made lip-to-lip upright frames are as; effect of bolt bending on the shear stiffness is insignificant, local deformation at the end of the bracing members contributes the most to the overall shear stiffness of the frames and effect of the upright bending stiffness on the shear stiffness is significant [7]. For back-to-back upright frames, bolt bending significantly influences the shear stiffness, axial deformation of bracings significantly influences the frame shear stiffness, effect of upright bending stiffness on shear stiffness is significant [7].

Vojko Kilar, Simon Petrovčič, David Koren, Simon Šilih [8] did Seismic analysis of an asymmetric fixed base and base-isolated high-rack steel structure [8]. The extended N2 method/pushover analysis was used and then the results obtained were compared with selected results obtained by nonlinear-dynamic analysis [8]. They mentioned that from the seismic point of view, full occupancy is not the critical condition, but lower occupancy, which could cause eccentricities ranging up to 10% or 15% of the larger floor plan dimension could leads to damage in some of the columns [8]. In this paper they show the direction sway resistance can provided in down aisle direction by the base-plate joints and by the joints between the stringers and uprights which are generally joined by bolts or boltless beam-end (tab) connectors. In this paper Nonlinear dynamic analysis (NLDA) is used to analyse the cold formed steel rack structure which include Inelastic time–history analysis. And second method was the extended N2 method i.e. pushover analysis based on methods originates mainly from their relative simplicity, in terms of modelling and computational demands, as well as from the interpretation of results, if compared with nonlinear dynamic analysis [8]. In this paper they conduct results on the basis of pushover analysis is that the results are presented for the whole building, as well as separately for the central rack structure and for the two frame supporting structures. It should be noted that the rack structure is not able to dissipate much energy, since a plastic mechanism occurs at the bottom of the uprights in practically all of the columns at the same time. It can also be seen that by assuming only rigid joints between the structural members result obtained as, the partially considered pinned joint connections, tend to be on the safe side if compared with the results [8]. Second result as Comparison of results of the N2 method with NLDA, extended N2 method can provide a good estimate of the displacements and drifts, and that it is also capable of detecting the main nonlinearities of the superstructure in the investigated test models with sufficient accuracy. For these reasons, the effect of varying mass eccentricity has been examined in the following section only by the extended N2 method [8]. And the last result was obtained by parametric study which is concluded that the base isolation system reduces the drifts by a factor of about 3, as was previously observed in the case of the relative displacements [8]. Conclusion of this paper was that the extended N2 method can provide good estimates of displacement and drifts and is also capable of detecting nonlinearities of the superstructure in the asymmetric FB and BI models [8]. Also conclude that pushover analysis underestimates the base displacement torsional amplifications in BI models. It is necessary in general to apply pushover analysis in both (positive and negative) directions in order to account for the same plastic hinge pattern as obtained by NLDA [8].

3. CONCLUSIONS:

All the above studies papers show that most of the racks are fail in upright direction and the most common cause of failure is seismic load. The pushover analysis is not such effective than that of time history analysis. It is also clear from the authors point is that the whole rack is not taken in consideration as the design and analysis of whole is complicated. So, for design and analysis purpose rack can be divide into two units; one is single-entry unit and second is double-entry unit.

Time history analysis and pushover analysis is considered as direct approach for analysis so, at the present time, the author understands that the direct approach i.e. Time history analysis and pushover analysis time history analysis is being seriously considered for inclusion in certain National design standards. The author believes that this is a positive step forward which should be encouraged.

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