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LITERATURE REVIEW

SECURING OF SAFETY BY MONITORING OF TECHNICAL PARAMETERS IN WAREHOUSE RACKS, IN HIGH-BAY WAREHOUSES AND HIGH STORAGE WAREHOUSES – LITERATURE REVIEW OF THE PROBLEM

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ABSTRACT. **Background**: The main objective of the paper is to develop a theoretical basis and a concept of the monitoring procedure of the technical parameters of warehouse racks, focusing on high-bay warehouses and high storage warehouses. Author describes potential plan for conducting his research based on simulation methods and, in the longer term, to conduct research based on existing objects (high-bay warehouses and high storage warehouses).
Material and methods: Simulation models in proposed research ought to be prepared based on analytical models specified in the literature. The simulation models are going to be investigated and subjected to numerical research of yield moments computing and evaluation, as well as shear stiffness and other parameters. Displacement of rack elements and settlement of racks are also going to be researched. Fatigue and wear of the elements are going to be analysed. The gained results are going to be subjected under statistical analyses.
Results: In the paper, theoretical discussion about subject matter is given.
Conclusion: In the light of the labour code, any warehouse manager is responsible for the safety of employees. Therefore, one should be aware, that even the racks of best design, which have been assembled incorrectly, in practice produce a large risk of a crash and generate equally large threat to the lives of employees working in its potential vicinity. The problem gets more severe in case of high-bay warehouses and high storage warehouses. Therefore, preparation of the monitoring procedure of the technical parameters of racks in warehouses is of highest priority, because of importance of human life and value of safety improvement.

Key words: safety, rack warehouse, high-bay warehouse, high storage warehouse.

INTRODUCTION

So far, the research conducted by the author has been focused on basic research methods and mathematical / physical modelling used for design of logistics facilities (different types of warehouses). Knowledge on warehousing, the development of methods and procedures to ensure the safety, maintenance and operational use of warehouses would be valuable contributions to design engineering aspects in high-bay warehouses and high storage warehouses (also taking into account the public access warehouses with customers access directly to warehouse racks, which is gaining popularity). Assurance of safety in warehouses of mentioned type, which is author's target, is secured through the monitoring of technical parameters of racks in two mentioned types of warehouses, and therefore the research would lead to increase of knowledge about the behaviour of major structures in a large cubature construction designs due to the widely understood external loads. Monitoring mentioned in the proposed solution in future

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would be described in the form of mathematical modelling. Further research will be executed by use of computer simulation methods. The issue is not thoroughly addressed in the literature, especially Polish one. Also, increasing number of logistics facilities of these types world-wide, convinces the author that it is necessary to develop knowledge on the relevant problems.

Nowadays, Logistics 4.0 defined by Jeschke Sabina (who is considered to be the originator of the concept of Logistics 4.0), as an integral part of Industry 4.0, might contribute to changes in logistics world – key terms such as smart logistics, digitalisation of the supply chain, or simply Industry 4.0 are widely discussed and these initiatives are current mega trends in management aspects of logistics and some of engineering research connected to logistics and transportation matters. She questions whether logistics companies are ready for such developments, as smart logistics or Logistics 4.0? What do companies need to do presently in order to be ready for the challenges in the future? A tremendous challenges to the transportation and logistics industry can occur, since the idea of Logistics 4.0 connects manufacturing companies, trade and consumers – and does so world-wide [Jeschke 2015, Jeschke 2016]. High-bay warehouses as well as high storage warehouse are chains and buffers in this global supply chain, which requires automation, as facilities in era of Logistics 4.0 are expected to be completely autonomous.

Logistics facilities such as high-bay warehouses are not very common in Poland, in contrast to high storage warehouses that are sometimes mistakenly considered as high-bay warehouses (argumentation is included in the next section of the paper). Private investigation based on discussion with Fijałkowski Janusz, the expert in warehouse designing, point out that there are only couple of such facilities (high-bay warehouses) in the country of Poland. Fijałkowski admits "[in Poland] steel structures [of that kind] have existed since 1975. One warehouse is placed in Ursus [district of Warsaw] and the other one is placed near city of Kutno," [Fijałkowski 2015]. When asked whether the one in Kutno is still in use, he admitted and added, that the diploma dissertation about optimisation of this particular warehouse exists [Fijałkowski 1980]. He claims, that it is planned to build new facilities of the kind. Therefore, it is anticipated, that in future in Poland there would be several logistics facilities such as high-bay warehouses. Unfortunately their designs, with a high degree of probability, will be based on foreign solutions. Taking after these mega trends, one must not divert one's attention from safety issues in logistics facilities, especially high-bay warehouses with their specific construction. Reasons mentioned above convinced the author to undertake research in the field of ensuring safety by monitoring the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses. It must be noted here that this paper announces future research on monitoring of technical parameters in warehouse racks, in high-bay warehouses and high storage warehouses. And it exposes state-of-mind of author in the research field. The case study connected to the subject matter will be published as separate paper.

POTENTIAL RESEARCH PROJECT OBJECTIVES

Rack elevations are one of the most common load-carrying warehouse infrastructure objects. A rack elevation is a very reliable construction, especially when high storage warehouses are considered. As it was remarked in the previous section of the paper, high storage warehouses are sometimes mistakenly considered as high-bay warehouses. To recall a definition of a high storage warehouse: it is a warehouse which maximum height is 14 meters according to [Kostrzewski 2013]. Meanwhile, a high-bay warehouse (HBW, in English it is called also as "high-rack warehouse" or colloquial "pallet silo", while in German is called as "Hochregallager" - HRL) is a warehouse which minimum height is 12 meters (or 14 meters according to [Kostrzewski 2013]) and currently the maximum height is about 50 meters according to [Voestalpine 2007], and which has a permanent building structure (usually this type of building is constructed of a steel structure but there are samples of reinforced concrete constructions) and

its storage infrastructure is a part of the supporting structure for walls (façade) and the roof of the warehouse. In the research, the author will refer mostly to a pallet rack, but also is planning to consider impact of walls and roof (which is especially important in the case of high-bay warehouses).

Pallet racks are liable load bearing structures, relatively much more heavily loaded than, for instance, floors of office part of a warehouse type of buildings. Therefore, safe structural design and correct modelling of the actual physical behaviour of such extraordinary steel structures are of the utmost importance, as well as safe operation conditions, which allow to avoid potential collisions caused by material handling equipment in the structural design.

In this paper, the author would like to propose an scientific approach to rack structure in aspects connected to mechanical engineering. The aim is to research distribution of forces and verify sagging or hogging moments in multi-bays, partly braced rack structure with several levels of storage in down-aisle direction (and across). It has to be done in order to show how forces and moments change under different heavy unit load distribution on shelves, how forces and moments change their values after destruction or simply exclusion of some elements in a rack structure.

The main objective of the proposed research is development of theoretical basis and the concept for the monitoring procedure of the technical parameters in warehouse racks for predefined high-bay warehouses and high storage warehouses. The author plans to conduct research based on simulation methods. Preparation and construction of simulation models for racks in warehouses is one of the steps which should forgo the selection of measurement points in warehouse racks based on numerical calculations and formulation of the requirements for monitoring procedure in selected measurement points. Having the measurement points selected, the simulation research on the effectiveness of formulated monitoring procedure would become possible. Positive outcome of this part of research would serve as a reason to install sensors and detectors in measurement points on racks elements in real-life warehouses and to conduct exploitation of the planned measurement system.

LITERATURE REVIEW AND THE STATE-OF-ART

The problem of technical parameters monitoring of racks in warehouses is generally connected to analysis and behaviour of steel storage racks and their elements. Nevertheless, it is highly important to familiarise with collapses of rack structure issues as well as with seismic behaviour of rack structure matters. As far as literature connected to pallet racks storage is concerned, a certain amount of research and papers is available and there are numerous analyses of behaviour of pallet racks in warehouses under different circumstances. Such behaviour is worth analysing, especially that according to [European Racking Federation 2010] influence of loading on a rack structure and changes of the load in time are not known because their monitoring is not customary. It is contrary to the buildings themselves, office-rooms etc. where freight loads impact on the structure and structural changes in time have been monitored and measured over numerous years thus making statistical evaluations possible. This has resulted in National and European standards specifying for instance floor, roof, wind and seismic loads, [European Racking Federation 2010: 7].

Authors of several research papers investigate pallet rack structures both in down-aisle and cross-aisle direction in warehouses. Wherein, more research deals with a down-aisle rack direction. [Baldassino and Bernuzzi 2000] consider influence of different types of beam-to-column joints by their numerical modelling on an overall rack frame response with reference to both service condition and ultimate limit states. Experimental analyses aimed at investigating behaviour of beam-to-column joints are continued in [Godley et al. 2000], as a part of a more general research project on seismic designing of pallet racks. Notwithstanding, authors of [Godley et al. 2000] present mathematical modelling for computerised analysis and designing of multi-

bay rack frame structures subjected to horizontal and vertical loads. The structures are analysed by considering an equivalent free-sway column and solving the differential equations of flexure. Consider influence of different types of beam-to-column joints by their numerical modelling on an overall rack frame response can be also find in [Król et al. 2014]. [Shah et al. 2016] compare experimental methods and analytical and design methods in aspects of consideration of beam-to-column connection in steel pallet rack. Separate topic is thin-walled cold-formed beam columns for steel storage systems in warehouse. This kind of research are focused on performance of some part racks only, however it is very important in racks designing (because these part of racks are heavy loaded with pallet load units) and in safety matters as well. These kind of analyses are presented in [Bernuzzi and Magenta 2015].

Research in which a cross-aisle rack direction is considered is less observed. Authors of [Sajja et al. 2008] and [Rao et al. 2004] consider side part of rack-frame researching of shear stiffness of rack frames, which is influenced by bracing pattern and connections between frame's elements. Meanwhile, [Petrone et al. 2016] consider cross-aisle rack direction in accordance to its seismic performance and response of rack structures, especially base connections of racks.

Authors of [Sarawit and Peköz 2006] very briefly compare rack structure designing methods and presents results, which show that the effective length method, in designing of industrial steel storage racks, is more conservative than the notional load method.

Separate subject in the literature, still related to designing and analyses, is a rack structure collapse, extremely dangerous occurrence, especially in case of high-bay warehouses. It is though, that consideration of dynamic kind of research is necessary. Prediction of behaviour of the rack structure is in fact possible only on analysis of technical parameters. Interesting collapse case study and scientific searching of its reasons are given in [Affolter et al. 2009]. Paper [Ng et al. 2009] is also worth studying. Authors present non-linear dynamic analysis of collapse prediction that includes effect of displacement on behaviour of the structure and multi-bay oscillation, while some parts of the rack structure are eliminated. Their paper is prefaced by research on stability of uprights in [Lau et al. 2003] and experimental investigation of pallet rack structures under sway in [Abdel-Jaber et al. 2006] and [Abdel-Jaber et al. 2005]. What is also observed, a new way of consideration of the problem connected to seismic matters in warehouse designing and secure operating has begun to be described in literature, as in [Franco et al. 2015]. The above topic concerns direct displacement based design of industrial rack clad buildings, [Haque 2012, Haque and Shahria 2013]. Interesting point of view in case of seismic aspects is given in [Bortolini et al. 2015]. Author propose strategy of pallet load units storage in warehouses in case of collapse prevention during seismic events. In general, seismic activity in Europe increases, therefore even in Poland new warehouse buildings' projects should take it into consideration. To prove the importance of that matter in area of Poland it should be mentioned that lately there were six seismic activities (Lower Silesia province; according to https://earthquake.usgs.gov, accessed on-line 16 December, 2016): 0km S of Grebocice, Poland, 2016-12-16 06:46:51 (UTC) - magnitude 4.5, 3km NNW of Grebocice, Poland, 2016-11-29 20:09:39 (UTC) - magnitude 4.3, 6km N of Lubin, Poland, 2016-10-17 23:50:33 (UTC) - magnitude 4.5, 5km SW of Grebocice, Poland, 2016-08-13 12:00:57 (UTC) - magnitude 4.7, 4km SE of Grebocice, Poland, 2016-07-30 19:10:37 (UTC) - magnitude 4.2, 1km WSW of Rudna, Poland, 2016-02-25 04:36:24 (UTC) - magnitude 4.2.

RESEARCH METHODOLOGY

As mentioned before, the main objective of the proposed research is development of theoretical basis and the concept of the monitoring procedure of the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses. In general, it needs

preparation and construction of simulation models for racks in warehouses.

It should be emphasised, that simulation modelling is just one type of possible research approaches. According to [Homburg 2007], four research methods are defined: empiricism, morphology, pure theory and modelling. Extensive discussion on the issues can be found in [Kemme 2013: 112-115]. Empiricism, morphology and pure theory can be omitted here as these research approaches are rarely used in technical and engineering research in general. In contrast to the three approaches mentioned above, modelling is highly recommended. It can be stated that two types of mathematical models are distinguished. They are analytical and simulation models – as it is mentioned in [Ashayeri and Gelders 1985: 285-294, Valkengoed 2004: 18]. „Analytical models are usually applied to obtain exact analytical solutions for planning problems rather simple systems. If a solution of such a mathematical model is available and is computationally efficient, it is usually recommended to study the model analytically rather than by a simulation model", [Kemme 2013: 113] after [Law and Kelton 2000: 5]. However, complex systems, such as rack warehouse systems, can sometimes not be easy to model their behaviour in analytical way, because they are not trivial. It is proposed that research is conducted based on simulation models.

Securing of safety by means of monitoring the technical parameters of racks in warehouses is generally connected to analysis and behaviour of steel storage racks and its elements. Therefore monitored storage racks should meet the requirements of the following standards (Polish Norms), among others:

- PN-88/M78320 - Storage Equipment. Storage Racks. Names, definitions, classification and symbols.
- PN-88/M78321 - Freestanding Storage Racks. Requirements and tests.
- PN-88/M78322 - Storage Equipment. Storage Racks. Basic parameters.
- PN-EN 15620:2008 Steel static storage systems – Adjustable pallet racking – Tolerances, deformations and clearances.

A number of Polish Norms have been withdrawn or replaced by others, therefore the practitioners are convinced that certain requirements contained in the documents mentioned earlier are now out of date because this norms are related to the documents, which have been withdrawn. Therefore, the proposed research might be treated as one of the first steps aiming at actualisation of Polish Norm.

In the light of the labour code, any warehouse manager is responsible for the safety of employees. Therefore, one should be aware, that the best made racks which have been incorrectly assembled, in practice produce a large risk of a crash, generating equally large threat to the lives of employees working in the vicinity of the potential occurrence (the point of view on the matter is based on [Central Statistical Office 2011, Central Statistical Office 2012, Central Statistical Office 2013]). And the problem even grows in case of high-bay warehouses and high storage warehouses. Therefore, preparing the monitoring procedure for the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses is believed to be unquestionably important.

Simulation models in proposed research ought to be prepared based on analytical models such as those given in [Lau et al. 2003, Abdel-Jaber et al. 2006, Abdel-Jaber et al. 2005, Lee et al. 2003, Bernuzzi and Maxenti 2015] (these are only examples, the comprehensive literature review is being continued). The simulation models are going to be subjected and investigated under numerical research of yield moments computing and evaluation, shear stiffness, other parameters and research of rack columns under sway. Displacement of rack elements and settlement of racks are also going to be researched. Fatigue and wear of elements are going to be analysed. At least, the developed results are going to be subjected under statistical analyses.

Practically, it is also important to take rack designing into consideration, therefore in the project analysis it can be taken into consideration as well. [Bernuzzi et al. 2015a] mention that racks elements' behaviour is significantly influenced by Wagner's

coefficients, warping torsion, and shear-centre eccentricity. They add that currently, these effects are neglected in routine rack design, owing to the absence of clear indications in standard provisions and the limited availability and knowledge of appropriate software tools supporting this complex design approach. They propose simplified approaches for the static design of medium-rise unbraced pallet racks in [Bernuzzi et al. 2015b], and they also considers seismic approaches in the second paper [Bernuzzi et al. 2015c]. Discussion and generalised comparison of racks designing approaches all over the world are given in [Bernuzzi 2015] and practical application of approaches mentioned in [Bernuzzi 2015] are given in [Bernuzzi et al. 2015a].

TASK TO BE REALISED WITHIN RESEARCH ON SAFETY ASSURANCE IN HIGH-BAY WAREHOUSES AND HIGH STORAGE WAREHOUSES

This paper presents a proposal for conducting research to ensure safety by monitoring the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses. The proposed research is divided into smaller tasks, specified below.

1. Development of the technical specification for the monitoring procedure for the technical parameters and racks in warehouses (including parameters measurement and analysis), in particular high-bay warehouses and high storage warehouses; identification of outer factors that will influence warehouse racks.
2. Development of theoretical basis and concept of the monitoring procedure of the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses – preparation of guidelines for the procedures in terms of the conception and selection of the necessary software (it might be stated that this task started to be realised – efforts are publish in [Kostrzewski 2013]).
3. Development and maintenance of a database of the technical parameters in the research – preparation of guidelines for the procedures in terms of the IT architecture.
4. Preparation and construction of simulation models for racks in warehouses, in particular high-bay warehouses and high storage warehouses.
5. Validation and verification of simulation models.
6. Selection of measurement points in warehouse racks based on numerical calculations and formulation of the requirements for monitoring procedure in selected measurement points.
7. Simulation research of the effectiveness of formulated monitoring procedure and participation in the development of simulation models.
8. Preparation of the technical documentation concerning the monitoring procedure of the technical parameters of racks in warehouses, in particular high-bay warehouses and high storage warehouses.

DISCUSSION

All research objectives given above are crucial as far as their feasibility is concerned. However, preparation and construction of simulation models for racks in warehouses, in particular high-bay warehouses and high storage warehouses can be the critical task therefore this task can postpone completion of the research. What is more, most of the tasks mentioned above need very detailed and specific knowledge, therefore a research team should be appointed. Specialists in different areas, such as mechanics engineers, electronic engineers, IT specialists, simulation experts, logistics consultants and others should be included in the research team.

Assumption of this kind of research plan should not be limited to mentioned tasks only. For example, stability of rack constructions should be included in the research.

Due to the fact that there are only few buildings of such type in Poland, it might be difficult to research on real-object logistics facilities.

CONCLUSION

Research on safety aspects of warehouse construction is a serious problem, especially when linked with safety aspects. The paper is an introduction into the subject matter and one of its aims is to signalise the need of ensuring safety in high-bay warehouse constructions before this kind of building will be constructed more often in Poland.

REFERENCES

Abdel-Jaber M., Beale R.G., Godley M.H.R., 2006, A theoretical and experimental investigation of pallet rack structures under sway, Journal of Constructional Steel Research 62 (1–2), 68-90. http://dx.doi.org/10.1016/j.jcsr.2005.04.008

Abdel-Jaber M., Beale R.G., Godley M.H.R., 2005, Numerical study on semi-rigid racking frames under sway, Computers & Structures 83 (28–30), 2005, 2463-2475. http://dx.doi.org/10.1016/j.compstruc.2005.03.020

Affolter Ch., Piskoty G., Wullschleger L., Weisse B., 2009, Collapse of a high storage rack, Engineering Failure Analysis 16 (6), 1846-1855. http://dx.doi.org/10.1016/j.engfailanal.2008.09.011

Ashayeri, J., Gelders, L.F., 1985, Warehouse design optimization, European Journal of Operational Research 21, 285-294. http://dx.doi.org/10.1016/0377-2217(85)90149-3

Baldassino N., Bernuzzi C., 2000, Analysis and behaviour of steel storage pallet racks, Thin-Walled Structures 37 (4), 277-304. http://dx.doi.org/10.1016/S0263-8231(00)00021-5

Bernuzzi C., 2015, European and United States approaches for steel storage pallet rack design: Part 1: Discussions and general comparisons, Thin-Walled Structures, 97, 308-320. http://dx.doi.org/10.1016/j.tws.2015.08.012

Bernuzzi C., Castiglioni C.A., 2001, Experimental analysis on the cyclic behaviour of beam-to-column joints in steel storage pallet racks, Thin-Walled Structures 39 (10), 841-859. http://dx.doi.org/10.1016/S0263-8231(01)00034-9

Bernuzzi C., Draskovic N., Simoncelli M., 2015a, European and United States approaches for steel storage pallet rack design. Part 2: Practical applications, Thin-Walled Structures, 97, 321-341. http://dx.doi.org/10.1016/j.tws.2015.08.011

Bernuzzi C., Gobetti A., Gabbianelli G., Simoncelli M., 2015b, Simplified approaches to design medium-rise unbraced steel storage pallet racks. I: Elastic buckling analysis, Journal of Structural Engineering 141 (11), 1-11. http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001271

Bernuzzi C., Gobetti A., Gabbianelli G., Simoncelli M., 2015c, Simplified approaches to design medium-rise unbraced steel storage pallet racks. II: Fundamental period estimates, Journal of Structural Engineering 141 (11), 1-13. http://dx.doi.org/10.1061/(ASCE)ST.1943-541X.0001278 , 04015037

Bernuzzi C., Maxenti F., 2015, European alternatives to design perforated thin-walled cold-formed beam–columns for steel storage systems, Journal of Constructional Steel Research 110, 121-136. http://dx.doi.org/10.1016/j.jcsr.2015.02.021

Bortolini M., Botti L., Cascini A., Gamberi M., Mora C., Pilati F., 2015, Unit-load storage assignment strategy for warehouses in seismic areas, Computers & Industrial Engineering 87, 481-490. http://dx.doi.org/10.1016/j.cie.2015.05.023

Central Statistical Office [Główny Urząd Statystyczny], 2013, Monitoring of The Labour Market – report [Monitoring Rynku Pracy – sprawozdanie], Department of Demographic and Labour Market [Departament Badań Demograficznych i Rynku Pracy]. http://www.stat.gov.pl/cps/rde/xbcr/gus/PW_wypadki_przy_pracy_2kw2013.pdf, accessed on-line: November 12th, 2013

Central Statistical Office [Główny Urząd Statystyczny], 2012, Monitoring of The Labour Market – report [Monitoring Rynku

Pracy – sprawozdanie], Department of Demographic and Labour Market [Departament Badań Demograficznych i Rynku Pracy]. http://www.stat.gov.pl/cps/rde/xbcr/gus/PW_wypadki_przy_pracy_2012.pdf, accessed on-line: November 12th, 2013.

Central Statistical Office [Główny Urząd Statystyczny], 2011, Monitoring of The Labour Market – report [Monitoring Rynku Pracy – sprawozdanie], Department of Demographic and Labour Market [Departament Badań Demograficznych i Rynku Pracy]. http://www.stat.gov.pl/cps/rde/xbcr/gus/PW_wypadki_przy_pracy_2011.pdf, accessed on-line: November 12th, 2013.

European Racking Federation, 2010, ERF Info, FEM 10/I-02, National Metalforming Centre.

Fijałkowski J., 2015, private correspondence of the paper author.

Fijałkowski K., 1981, Racjonalizacja transportu w strefie dostawczo-odbiorczej magazynu wysokoregałowego 'Agroma' w Kutnie [Rationalisation of transport in the delivery/receiving area in high-bay warehouse of 'Agroma' company in Kutno city], Master thesis, Warsaw University of Technology, Warsaw.

Franco A., Massimiani S., Royer-Carfagni G., 2015, Passive Control of Steel Storage Racks for Parmigiano Reggiano Cheese under Seismic Accelerations, Journal of Earthquake Engineering, 19 (8), 1222-1259. http://dx.doi.org/10.1080/13632469.2015.1049386

Godley M.H.R., 1997, Plastic design of pallet rack beams, Thin-Walled Structures 29 (1–4), 175-188. http://dx.doi.org/10.1016/S0263-8231(97)00021-9

Godley M.H.R., Beale R.G., Feng X., 2000, Analysis and design of down-aisle pallet rack structures, Computers & Structures 77 (4), 391-401. http://dx.doi.org/10.1016/S0045-7949(00)00031-6

Haque A.B.M.R., 2012, Seismic design of industrial rack clad buildings, Master thesis, The College of Graduate Studies (Civil Engineering), The University of British Columbia (Okanagan).

Haque A.B.M.R., Shahria A.M., 2013, Direct Displacement Based Design of Industrial Rack Clad Buildings, Earthquake Spectra, Earthquake Engineering Research Institute. http://dx.doi.org/10.1193/080611EQS195M

Homburg C., 2007, Betriebswirtschaftslehre als emprirische Wissenschaft – Bestandsaufnahme und Empfehlungen [Business Economics as an Empirical Science - Inventory and Recommendations], Zeitschrift für betriebswirtschaftliche Forschung [Journal of Business Research] 56 (7), 27-60.

Jeschke S., 2016, Logistics 4.0 - Artificial Intelligence and other modern trends in transport and logistics, October 19th 2016, XIII Forum Polskich Menedżerów Logistyki POLSKA LOGISTYKA [XIII Forum of Polish Logistics Managers POLISH LOGISTICS], Centrum Zarządzania Innowacjami i Transferem Technologii Politechniki Warszawskiej [Center for Innovation Management and Transfer of Technology in Warsaw University of Technology], Warsaw.

Jeschke S., 2015, Towards Logistics 4.0 – Distributed Systems with Decentralized Control Paradigms. Available from internet: http://www.ima-zlw-ifu.rwth-aachen.de/fileadmin/user_upload/Institutscluster/Publikation_Medien/Vortraege/download//Lufthansa_11Juni2015.pdf, accessed on-line: October 27th, 2016.

Kemme N., 2013, Design and Operation of Automated Container Storage System, Physica-Verlag, A Springer Company, Springer-Verlag Berlin Heidelberg.

Kostrzewski M., 2013, Loads Analysing In Pallet Racks Storage Elevation, CLC 2013: Carpathian Logistics Congress - Congress Proceedings (reviewed version), 260-265.

Król P.A., Papadopoulos-Woźniak M., Wójt J., 2014, Experimental Tests on Semi-rigid, Hooking-type Beam-to-column Double-sided Joints in Sway-frame Structural Pallet Racking Systems, Procedia Engineering 91, 238-243. http://dx.doi.org/10.1016/j.proeng.2014.12.053.

Lau H.H., Godley M.H.R., Beale R.G., 2003, The influence of base connectivity on the ultimate load of columns, Computers & Structures 81 (18–19), 1827-1849. http://dx.doi.org/10.1016/S0045-7949(03)00205-0

Law A.M., Kelton W.D., 2000, Simulation modelling and analysis, third edition, MA: McGraw Hill, Boston.

Lee Y.H., Lee M.H., Hur S., Optimal design of rack structure with modular cell in AS/RS, International Journal of Production Economics 98 (2), 172-178. http://dx.doi.org/10.1016/j.ijpe.2004.05.018

Ng A.L.Y., Beale R.G., Godley M.H.R., 2009, Methods of restraining progressive collapse in rack structures, Engineering Structures 31 (7), 1460-1468. http://dx.doi.org/10.1016/j.engstruct.2009.02.029

Petrone F., Higgins P.S., Bissonnette N.P., Kanvinde A.M., 2016, The cross-aisle seismic performance of storage rack base connections, Journal of Constructional Steel Research, 122, 520-531. http://dx.doi.org/10.1016/j.jcsr.2016.04.014

Polish Norms, 1988, PN-88/M78321 - Freestanding Storage Racks . Requirements and tests.

Polish Norms, 1988, PN-88/M78322 - Storage Equipment. Storage Racks. Basic parameters.

Polish Norms, 2008, PN-EN 15620:2008 Steel static storage systems – Adjustable pallet racking – Tolerances, deformations and clearances.

Rao S.S., Beale R.G., Godley M.H.R., 2004, Shear stiffness of pallet rack upright frames, Seventeenth International Specialty Conference on Cold-Formed Steel Structures, Orlando, Florida, USA, November 4th-5th, 2004, 18 pages.

Sajja S.R., Beale R.G., Godley M.H.R., 2008, Shear stiffness of pallet rack upright frames, Journal of Constructional Steel Research 64 (7–8), 867-874. http://dx.doi.org/10.1016/j.jcsr.2008.01.025

Sarawit A.T., Peköz T., 2006, Notional load method for industrial steel storage racks, Thin-Walled Structures, 44 (12), 1280-1286. http://dx.doi.org/10.1016/j.tws.2007.01.003

Shah S.N.R., Ramli Sulong N.H., Jumaat M.Z., Shariati M., 2016, State-of-the-art review on the design and performance of steel pallet rack connections. Engineering Failure Analysis 66, 240-258. http://dx.doi.org/10.1016/j.engfailanal.2016.04.017

Valkengoed M.P.J., 204, How passing cranes influence stack operations in a container terminal: a simulation study, Diploma Thesis, University of Amsterdam.

Voestalpine, 2007, Available from internet: http://www.voestalpine.com/finaltechnik/de/products/storage_technology/highbay_warehouse/highbay_warehousing.html, accessed on-line: January 5th, 2007.

ZAPEWNIENIE BEZPIECZEŃSTWA POPRZEZ MONITOROWANIE PARAMETRÓW TECHNICZNYCH REGAŁÓW MAGAZYNOWYCH, W MAGAZYNACH WYSOKOREGAŁOWYCH ORAZ MAGAZYNACH WYSOKIEGO SKŁADOWANIA – PRZEGLĄD ZAGADNIENIA W LITERATURZE

STRESZCZENIE. **Wstęp:** Głównym celem proponowanego w artykule projektu jest opracowanie podstaw teoretycznych i koncepcji procedury monitorowania parametrów technicznych regałów w magazynach, w szczególności wysokoregałowych i wysokiego składowania.
Metody: Autor planuje realizować projekt przy zastosowaniu metod symulacyjnych, a w dłuższej perspektywie prowadzić badania na rzeczywistych obiektach. Realizacja badań następować będzie w oparciu o obliczenia numeryczne i formułowanie wymagań dla procedur monitorowania w wybranych punktach pomiarowych na regałach.
Wyniki: W artykule przedstawione zostały teoretyczne rozważania na temat tytułowego przedmiotu badań.

Wnioski: Błędnie zmontowane lub niepoprawnie użytkowane regały magazynowe wywołują duże ryzyko wypadku, a zatem stanowią zagrożenie dla życia pracowników i mienia. Przygotowanie procedury monitorowania parametrów technicznych regałów w magazynach jest zatem bardzo ważne.

Słowa kluczowe: bezpieczeństwo, regał magazynowy, magazyn wysokoregałowy, magazyn wysokiego składowania

DIE GEWÄHRLEISTUNG DER SICHERHEIT DURCH DIE ÜBERWACHUNG DER TECHNISCHEN PARAMETER VON REGALANLAGEN IN HOCHREGALLAGERN UND HOCHLAGERN – EINE FACHLITERATURÜBERSICHT

ZUSAMMENFASSUNG. Einleitung: Das Hauptziel des im Artikel vorgeschlagenen Projektes ist die Entwicklung von theoretischen Grundlagen und Verfahrenskonzepten für die Überwachung der technischen Parameter von Regalanlagen in Lagerhallen, insbesondere in Hochregallagern und Hochlagern.
Methoden: Der Autor plant es, das Projekt einleitend unter Anwendung von Simulationsmethoden durchzuführen. In Zukunft wird die Forschung auf reale Objekte implementiert werden. Die Umsetzung der Forschung wird auf der Grundlage von numerischen Berechnungen beruhen. Die Anforderungen für Überwachungsverfahren werden an ausgewählten Messstellen innerhalb der betreffenden Regalanlagen formuliert.
Ergebnisse: Der Artikel stellt die theoretischen Überlegungen zum Thema der betreffenden Studie dar.
Fazit: Falsch oder nicht ordnungsgemäß montierte Regale stellen ein hohes Unfallrisiko dar und somit läuft gegebenenfalls die Gefahr eines Arbeitsunfalls und/oder einer Körperverletzung oder eines Todesfalls innerhalb des tätigen Mitarbeiterteams sowie möglichen Auftretens von Eigentumsschäden. Die Vorbereitung und Ausarbeitung der Verfahren für die effektive Überwachung von technischen Parametern der Regalanalgen in Lagern aller Art sind daher von größter Bedeutung.

Codewörter: Sicherheit, Regalanlagen, Regallager, Hochregallager, Hochlager

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