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Safety related study of Expanding Pin systems application in lifting and drilling equipment within Construction, Offshore, and Marine sectors

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Abstract. A questionnaire-based survey has been performed among original equipment manufacturers (OEMs), sub-suppliers, engineering companies, end-users, service & maintenance, and “others”, as part of an investigation to clarify their relationship to expanding pin system, compared to standard, cylindrical pins. In addition, a short literature study on onshore cranes is conducted. The survey is based on 9 questions about safety for personnel and machine, breakage, and wear of pins and supports, and installation and retrieval easiness of pins. The analysis of the responses indicates that safety for personnel and machines/equipment is regarded mainly as either “Important” or “Crucial and decisive”, and that the expanding pin solution is regarded as “better” or “equal” compared to the standard, cylindrical pin, both for “safety level”, “risk for breakage of pin & support”, “tear & wear on pin & support” and “installation and retrieval time”.

Keywords: Expanding pins, heavy equipment, tear and wear, breakage, lifetime, downtime, safety

1. Introduction

Almost any kind of heavy equipment in almost any type of industry has shear pins in the joints to make movements possible between the different parts. These joints are typically called Rotary Joints where the Revolute Joints ideally provide 1 Degree of Freedom (DOF) and the Spherical Joints provide up to 3 DOF. A cylindrical pin in a joint will normally have some installation clearance, which remains and increases during operation due to wear and compression of the support bore surface. The increased clearance in combination with axial loading, planned or unplanned, rotational, and normal radial loading from its operation, can result in a multi-axial stress distribution at the pin and bore surface [1,2]. This is especially the case when the support or lug material is of higher strength steel, which is a common way of reducing the equipment total weight and increase the lifting or loading capacities. Such multi-axial stress patterns from the combination of normal stresses and tangential stresses can result in fretting crack initiation and propagation, with a rupture of the support as a possible result, with increased risk of damage and fatalities. This phenomenon is well known and documented and called fretting fatigue failure and could reduce the component lifetime considerably under the right conditions [3,4]. Talmi et al. [1] concluded that the fretting fatigue mechanism is the dominating failure mechanism in a pin



joint subjected to cyclic loading conditions, by comparing their extended finite element (XFEM) results with observed results from the literature.

Lifting and hoisting equipment such as cranes are often subject to strict rules and certifications due to the nature of the operations they are performing, and the risks involved. The dynamic loading could increase the stress level up to two times, or more [5], depending on the operational loads and internal joint clearance, and a twenty-fold increase in accelerations of pin movements. Lagerev and Lagerev [5,6] have investigated ways to increase the life of hinge lugs by eliminating backlash by use of elastic damping, and other techniques are to implement antifriction bushes, polymer coatings or different hardening methods on the adjacent contact surfaces [7]. Another technique to control rapid movements and reduce the dynamic reaction forces in the joints is the heave compensation approach [8-11], typically for offshore, maritime, floating wind cranes, and sub-sea operations. A floating structure such as a ship can have six degrees of movement; a) heave, b) sway, c) surge, d) roll, e) pitch, and f) yaw, which all can affect negatively lifting and loading operations. Without a compensation system, such uncoordinated relative movements can generate high dynamic and shock loads into the equipment and specially into the pinned joints, who can suffer friction wear, corrosion wear, fretting wear, and deformations which again can result in increased play in the joint, see Figure 1 (a), or even breakage of the pin.

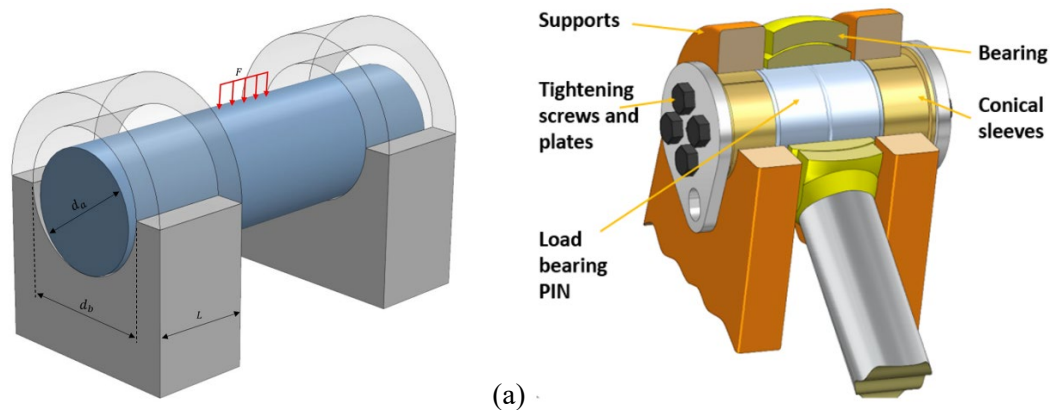


Figure 1. An illustration of pin in support – (a) standard cylindrical pin, and (b) expanding pin

The purpose of this study is to analyse the importance of use of expanding pins, Figure 1 (b), related to safety for personnel, equipment, and environment, on cranes, drilling equipment, and other heavy machinery. The study is based on analysis of previous publications, investigations, and reports, in addition to a questionnaire-based survey [14], and communication with some companies operating in the Norwegian and global energy area.

2. Background and applications of expanding pin systems

2.1. Background

Any heavy lifting equipment within any industry involving standard cylindrical shear pins will be exposed to a relative movement between pin and support with the wear issues it brings, due to the diameter difference between the pin and the support bore, typically for installation purposes. The expanding pin system [12,13] has got the ability to expand towards the support bore surfaces and lock the pin with a radial wedge pressure, and by that eliminate the wear issues at the pin – bore contact surfaces. Normally the wear problems occur at the support bores surfaces which normally have a lower steel quality grad, see Table 1, but the pin which has a higher strength and harder surface can suffer breakage if the shock loads are increased over maximum design value.

An expanding pin will lock the pin 360° to the support during the complete operation, independent of external load size and direction and thereby prevent the wear-risk experienced in the standard cylindrical pins. The steel qualities of the bearing element of an expanding pin will be customized, but

normally of same quality as the cylindrical pin, as shown in Table 1 [14]. The risk to be exposed to wear for the expanding pin solution and for a cylindrical one is different, and both are shown in Figure 2.

Table 1. Physical properties of typical pin and support materials for heavy machinery

Steel grade:	Typically use:	Yield, $R_{p0.2}$ min. [MPa]	Tensile, R_m min. [MPa]	Size range [mm]
S355 (EN 10025-3)	Supports	355	470	40 - 80
S420 (EN10027-2)	Supports	370	520 - 680	63 - 80
42CrMo4+QH (EN10083-3)	Pin	650	900	$\leq \text{Ø}100$
34CrNiMo6+QH (EN10083-3)	Pin	800	1000	$\leq \text{Ø}100$
30CrNiMo8+QH (EN10083-2)	Pin	900	1100	$\leq \text{Ø}100$
S17-4 PH D1150 / 1.4542	Pin	725	930	-
S165M / 1.4418	Pin	700	900-1100	-

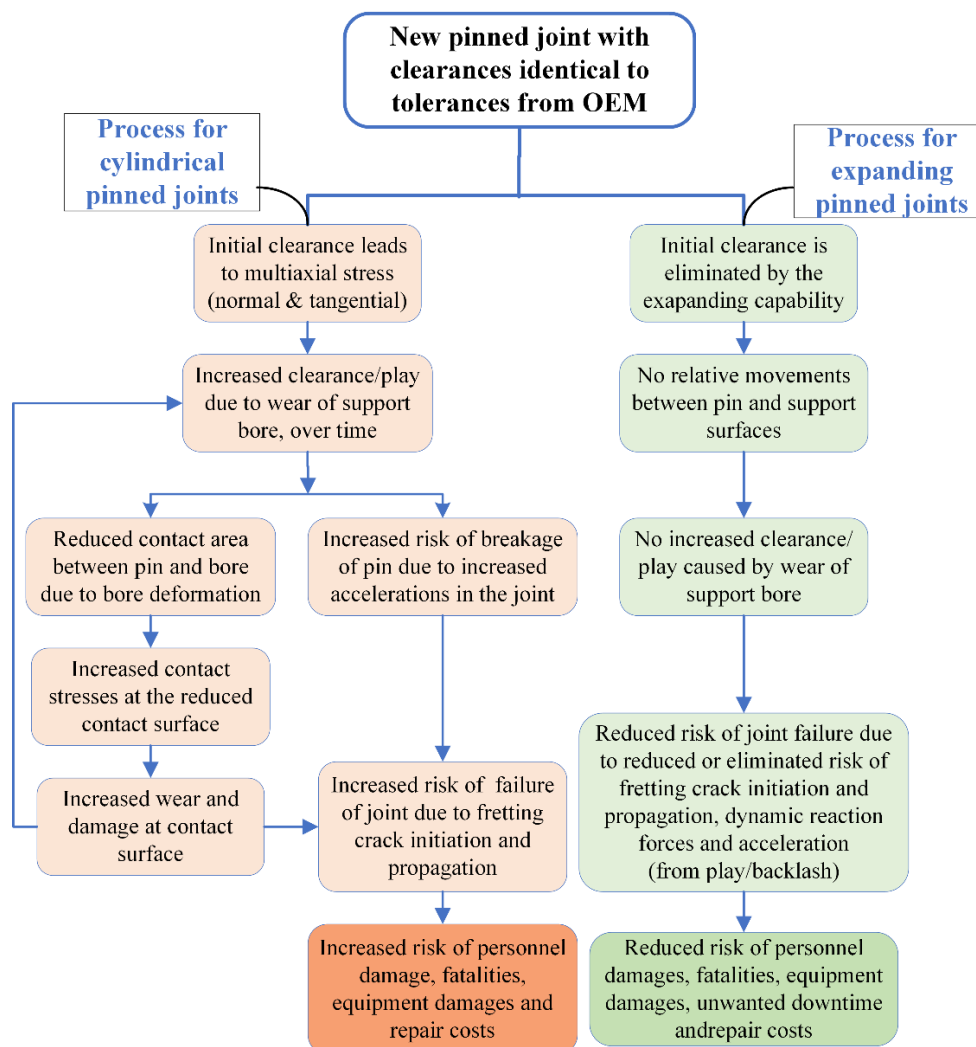


Figure 2. Load - failure processes for cylindrical pinned joints and expanding pinned joints (arrows indicate the outcome)

Typical support materials can be S355 construction steel or S420 quality, which is a high strength weldable structure with fine grain steel quality. For some specific grades, it can reach high impact properties at temperatures as low as -50°C . The pin is often exposed to high, oscillating, dynamic or

even shock loads, and it serves as an important and critical connection element between different parts of the machine. The pin material is therefore normally of a higher strength steel grade than the supports, often of quality 42CrMo4+QH, 34CrNiMo6+QH, 30CrNiMo8+QH, 17-4 PH, or S165M / 1.4418, whose physical properties are given in Table 1 [14].

A standard pin will have a contact surface and pressure with the support bore up to a maximum width of 180° with changing direction depending on the external load size and direction, which results in a stick-slip situation moving around, also depending on external load size and direction. Any initial damage or deformation of the support bore will increase and accelerate the damage of the joint, see Figure 2.

2.2. Applications of expanding pin systems

The expanding pin system can be applied in any joint where a standard cylindrical pin can be used but is normally considered in positions where there is problem or potential issue that cannot be resolved by the traditional solution. Such issues can be vibrations, shock loads, challenges with wear and fretting, requirements for quick and safe installation and retrieval of pins, and low life-costs and high production rate. The expanding pin is widely applied in drilling equipment both offshore and onshore, offshore cranes and maritime cranes, maritime hatches, winches, and rudder systems, within paper and steel mills, construction vehicles and mining equipment, and even in the space industry. The pin system is relatively well known within the Norwegian OEMs (Original Equipment Manufacturer) of maritime and offshore cranes, and drilling equipment, and considered as the safest, quickest, and most economical solution [14].

3. Research methodology

A questionnaire-based survey was sent to 256 potential responders during the first weeks and months of the COVID-19 pandemic in 2020, and 58 responded. A study based on that survey was published in 2021 [14], and this investigation is partly based on some of the responses from the original survey. The responders in the original survey were from 10 different countries with companies from Norway as the main group (67%). In addition, there are companies from Sweden, Canada, Scotland, Greece, Brazil, Finland, The Netherlands, USA, and Germany. The different responders operate in various markets as, (a) Offshore Oil&Gas, (b) Maritime, (c) Subsea, (d) Dredging, (e) Mining onshore & offshore, (f) Construction & earth moving, (g) Specialized machines and equipment, (h) Steel and paper industry, and (i) Other. In this study, only the following segments are included: (a), (b), (c), (d) and (f), and some of the companies have activities in more than only one of the segments. The survey was directed to persons and positions with responsibility related to pin solutions, or related machines and equipment.

In addition, a short literature study on safety and accidents with construction cranes was performed to better understand the importance of pins in such events. The third part of the research is based on a short questionnaire answered by three national and international energy companies established in the Stavanger region, Norway.

4. Literature study and survey

As part of this study, a short literature study on accidents with onshore construction cranes, mainly tower cranes, was performed, together with a look into the Norwegian and foreign Petroleum and Offshore & Maritime sectors.

4.1. Onshore construction cranes

Three Hammerhead Tower cranes of same model collapsed [15] the same day, within hours of each other, in Miami and Fort Lauderdale on September 10th, 2017, during the Hurricane Irma. More specifically, the common failure of the three cranes was the detachment of the crane jibs from their turntables due to turbulent wind loads. The bottom of the tubular framed tower top was attached with pins at four locations at the top of the turntable. The long pendants consist of several shorter pieces, connected with pins. The bottom chords of the jib were pinned to the turntable, and the counter jib was

connected to the turntable also with pins. During the heavy winds the jib came off the pinned connection, and two pins failed when the cotter pins loosened, for all three cranes.

Peraza and Travis [16] investigated the rapidly changing regulations and presented a review of crane accident statistics at a local (New York) and national (USA) level. In the period from 1992 to 2006, there were an average of 42 construction worker fatalities per year, which had increased to 54 in 2008. Seven crane related accidents were analysed with the 540 feet high “Big blue” crane with rated lifting capacity of 500 tons as the biggest one. These accidents resulted in some legislation changes in regulation of tower crane operations, and it was imposed additional requirements for testing of specific critical crane components, as joints, pins, and bolts. This shows the importance of pins and bolts as critical elements in cranes, where increased clearances between pin and support generates increased dynamic reaction forces and highly increased accelerations. Such increased dynamic forces could surpass the bolts design loads and initiate fretting wear issues at the bore surface.

The Department of Occupational Safety and Health in Malaysia sent out a Safety Alert [17] in 2017 regarding a tower crane accident, due to failure of counter jib platform connection pin, see Figure 3. The safety alert indicates the breakage of the two cylindrical pins as the main reason for the accident, without further explanations.



Figure 3. Tower crane accident – (a) crane after accident, and (b) broken pins

The UK Government through Health and Safety Executive (HSE) aims to reduce work-related death, injury, and ill health, and requested Health and Safety Laboratory (HSL) to prepare a report [18] about tower crane incidents around the world between 1989 and 2009, and if possible, specify the reason for each incident and the crane involved. The background for requiring the report was five major crane accidents in the UK between 2000 and 2009, where subsequent investigation revealed that the collapses were due to different causes. The report contains information about 85 incidents and is categorized with percentage distribution of incidents as follows: Erection/dismantling/extending of the crane (34%), Extreme weather (18%), Foundation issues (2%), Mechanical or structural issues (5%), Misuse (7%), Electrical/control system issues (1%), Unknown cause (33%).

It is worth to notice that 85% of the incidents are within 3 of the 7 categories, erection / dismantling / extending, mechanical / structural and unknown cause, where the latter has 33% of all the incidents, which means that it was impossible with the given information to define the exact reason for the accident. In general, it was also discovered that the reason for the failures or the incidents often are described as the immediate consequences more than a possible original or root cause. Descriptions as “the crane fell to the ground”, “the top had parted from the mast section”, “during dismantle the crane collapsed”, “the structure gave away”, “strong wind blew the jib over the A-frame”, “counterweight collapsed first, followed by the main jib”, and “it was believed that...”, “reports suggest that...” are much used, but not completely accurate explanations.

The expression “a normal accident” seems to exist within the industry and originates from Charles Perrow [19] where the expression represents a “sociological explanation for accidents in complex technological systems” [20]. Certain accidents were called *normal accidents* or *system accidents* because they seemed to be inevitable in highly complex systems due to a multiple number of trivial and

“unimportant” initial failures which interact with each other in unpredictable ways, to finally cause major or severe accidents. It has been noted that some investigations or reports on crane incidents use the explanation of “normal accident” instead of giving a more specific reason.

4.2. The Norwegian and foreign Petroleum and Offshore & Maritime sectors

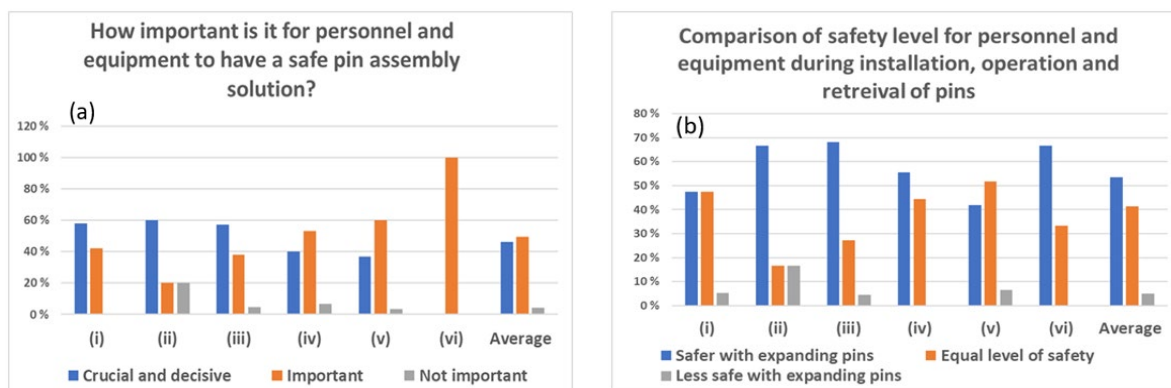
The Offshore and Maritime sectors have a wide range of equipment applying or having a potential for applying expanding pin solutions [14], among them; offshore and maritime cranes with and without motion compensator systems, A-frames both at foot/leg connection and at hydraulic cylinders, power driven winches, anchor systems, hatches, rudder systems, Dollies, travelling blocks, pipe handler cranes, and excavators. Such equipment is normally subjected to comply with certain standards and certifications to be allowed to be in use. These standards and certifications can typically be NORSOK based [21], with the following treating lifting activities; R-002 (Lifting Equipment), R-003 (Safe use of lifting equipment), and R-005 (Safe use of lifting and transport equipment in *onshore* petroleum plants), and a variety of other standards within Drilling, Mechanical work, etc., in addition to third party certification and classification bodies as Lloyd’s Register, different TÜV bodies, DnV, ABS and others.

The Petroleum Safety Authority (PSA) is an independent government regulator with responsibility for safety, emergency preparedness and the working environment in the Norwegian petroleum industry, and its regulations can be found at the Standards Norway web page [21].

Non-compliance with the required and statutory laws, regulations and standards could have serious consequences, such as (a) stop in production and / or operations based on own decision or by direct order from PSA, (b) problems with the license to operate, (c) police or PSA investigations resulting in fines from authorities and (d) loss of reputation in the market, according to various energy companies operating in the Stavanger region (Norway). The personnel health, safety and life are extremely important and there will normally not be accepted any situations which can affect that negatively.

4.3. Questionnaire-based survey regarding pin solutions for lifting and drilling equipment.

Safety, and safe and secure operations and equipment, often focus on quality of procedures, training, tools, and equipment, but should also focus more on how to prevent damages in pinned joints and ease installation and retrieval jobs. This survey reveals how the involved companies value safety for personnel and equipment in general, how safe the expanding pin solution is compared to the standard cylindrical pin, and their capabilities when it comes to tear, wear, breakage and easiness of installation and retrieval, see Figure 4. The types of involved companies are OEM (i), supplier to OEM (ii), engineering (iii), end-user (iv), service & maintenance (v), or others (vi).



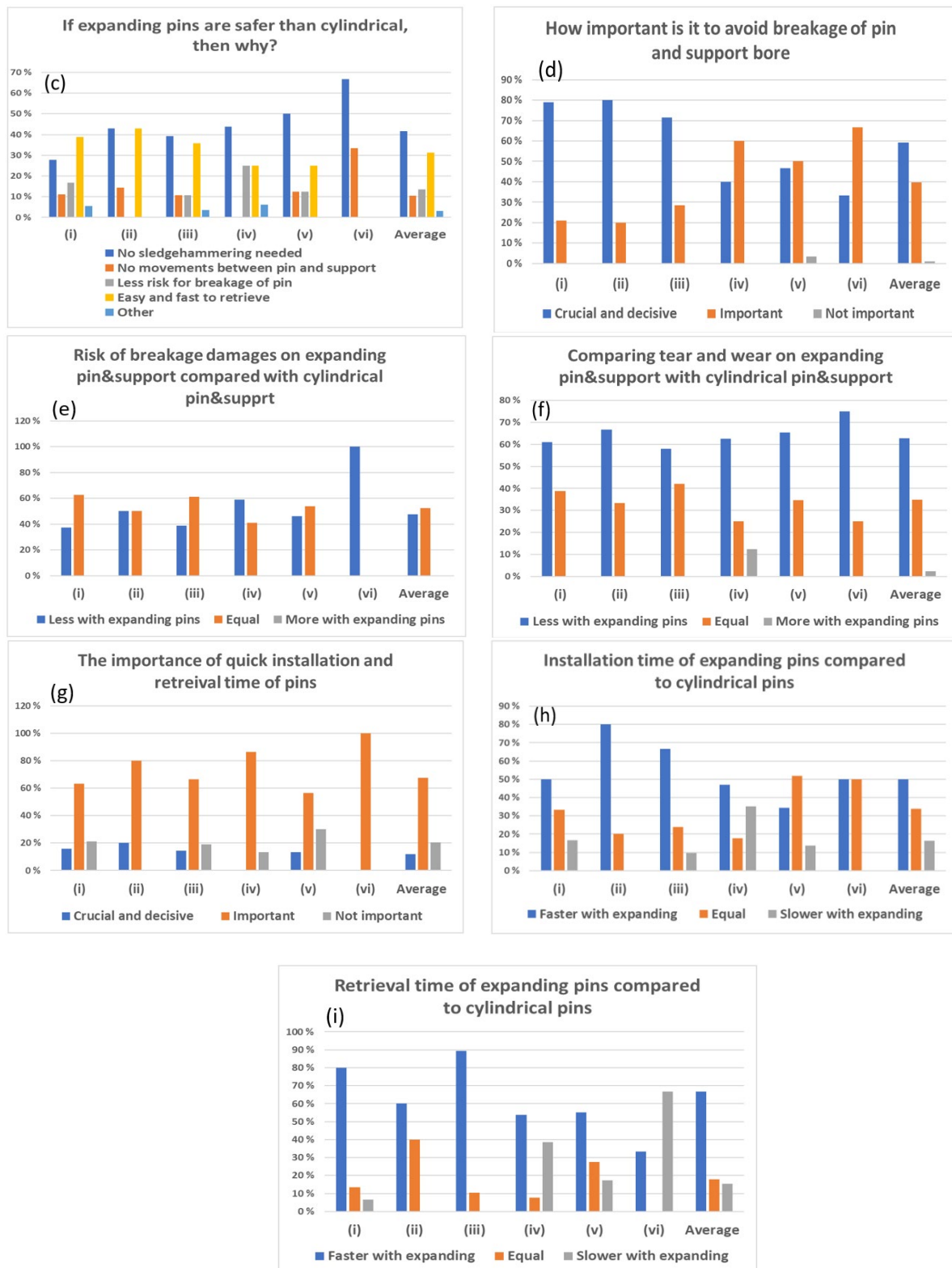


Figure 4. Statistics from questionnaire-based survey – (a) the importance of safe pin solution, (b) comparison of safety levels, (c) why safer with expanding pin, (d) the importance of avoid breakage, (e) risk of breakage, (f) comparing tear and wear with different pins, (g) the importance of quick pin installation and retrieval, (h) installation time, and (i) retrieval time

5. Analysis, discussions of results and outlooks

Analysis of previous crane incidents, specially within onshore construction tower cranes, indicate that pins and bolts play an important role within the machinery, to keep each part in its position, but the pin – support interaction itself is seldomly focused on. Although pins and bolts are relatively small units they are of extreme importance when it comes to criticality in relation to safe and sound operations, both for mechanical equipment and for people working in the proximity. A standard cylindrical pin will over time damage the joint supports by deforming and making the support bore bigger and oval, which can result in unstable and less controllable operations, less accuracy in lifting operations, unwanted high accelerations and shock reactions in the joints and increased risks for both the equipment and personnel. The relative movements between pin and support and slip-stick contact over time increases the risk of failure due to fretting crack initiation and propagation.

When an incident happens, it seems to be explained with *strong winds, the jib or counterweight collapsed, the structure gave away*, or even simply as *normal accidents*. Undoubtedly this happens, but the explanation of *normal accident* seems to be used as a substitute of a more in-depth investigation. It seems like it never is performed analysis of the negative consequences the play between pin and support in a joint can have on such tower crane accidents, or how the incident could have developed if the play had been eliminated by an expanding pin system. The effect of an important reduction of accelerations and dynamic reaction forces in the crane joints should be of interest to analyse both before and after these accidents.

The questionnaire-based survey gives some interesting relationships between the participants view on safety, and the different pin solutions, divided into which area they belong, being OEM (i), supplier to OEM (ii), engineering (iii), end-user (iv), service & maintenance (v), or others (vi). It is a 96% score as *Crucial and decisive*, and *Important*, see Fig. 4 (a), on the question of “How important is it for personnel and equipment to have a safe pin assembly solution”, where OEM/Production (i/ii) and Engineering (iii) score highest on *Crucial and decisive*. This shows how the stakeholders value the importance of safety when it comes to pinned joints.

On the question of *safety level*, Figure 4 (b), the responders evaluate the safety level, as they define and experience it, for personnel and equipment, during installation, operation, and retrieval of pins, for the two different pin solutions in question. Figure 4 (c) shows the results from a following-up question for those who responded that the expanding pins are safer. Four specific alternatives plus one open (Other) are given, and the results show 97% of the responders chose the given alternatives, and only 3% gave an alternative reason. The responders’ main concerns regarding safety is related to personnel and equipment, and their economic appraisals and concerns are reported in a study by Karlsen and Lemu [14].

As demonstrated in Fig. 4 (b), 54% aimed at the expanding solution as the safest, and only 4% stating this pin as less safe. The stakeholder (ii), (iii), (iv) and (vi) clearly indicate this with a 65% average score on *Safer with expanding pins*. The reasons for *why* the expanding pin is considered safer Fig. 4 (c), there are two main reasons given, (1) *No sledgehammering needed*, and (2) *Easy and fast to retrieve*. These are the main reasons for all the defined stakeholders, (i) – (v). Retrieval of pins which are stuck in the support bore, due to cold-welding, corrosion, or deformation can be a high-cost and high-risk operation, with use of high-pressure hydraulic tools, flame-cutting equipment, welding and line-boring. Pin solutions which can prevent such high-risk operations are highly evaluated by the stakeholders.

For all the participants, the *importance of avoiding breakage* is naturally highly valued, with OEM (i), supplier to OEM (ii) and engineering (iii) scoring 79%, 80% and 71% on *Crucial and decisive*, with the others almost equally divided between *Crucial and decisive*, and *Important*, see Fig. 4 (d).

When it comes to the *risk of having pin/support breakage*, Fig. 4 (e) and/or *wear issues*, Fig. 4 (f), there is no one (0%) indicating that expanding pins are more exposed to breakage, than the std pin. It is relatively equally divided between *Less with expanding pins* and *Equal*, with 48% and 52% as total values, respectively. Analysing the tear and wear comparison between expanding pins and cylindrical ones, it shows that within each of the stakeholder segments (i) – (vi) in Figure 4 (f), it exists a clear

opinion and experience that there is less wear issues with expanding pins compared to standard pins, with 63% and 35%, respectively. Only 2% see more wear issues with expanding pin solutions.

The stakeholders have a clear opinion on the *importance of quick* installation and retrieval of pins, Fig. 4 (g), with 80% indicating that as *Crucial and decisive*, and *Important*. Service, Repair and Maintenance (v) have the highest score on *Not important* with 30%.

When comparing *installation and retrieval time* for expanding and cylindrical pins, Fig. 4 (h) and (i), respectively, most of the stakeholder segments (Figure 4 (h) (i) – (iv)) responds that the expanding pins are the fastest to install, and the total average states 50% for expanding pins as fastest, 34% as equal, and 16% stating standard pins as fastest. For the retrieval time the stakeholder segments (i) – (v), Figure 4 (i), responds that the expanding pin is the fastest to retrieve, and the corresponding numbers for the total average are 67%, 18% and 15%, respectively.

OEM/Production (i/ii) and Engineering (iii) score lowest on the statement *Slower (retrieval) with expanding pins* with 7%, 0% and 0%, respectively.

Although the survey got feed-back from 58 responders it is limited to those who have some practical knowledge or experience with expanding pin solutions, but very little information from scientific investigations and studies around expanding pin solutions. It would increase the knowledge if more scientific work in combination with real case studies were performed.

6. Conclusion

Expanding pin solutions seems to be recognized as a safer pin solution compared to standard cylindrical pins, specially within the Offshore and Maritime segments, where the safety is valued highly by all the stakeholders. The stakeholders in this survey are both OEM, suppliers to OEM, Engineering companies, End-users, and Service companies. The fact that there is, in general, no need for sledgehammering to get the pin in or out of the joint, given its capability to expand after installation and contract before retrieval, makes the solution score high on safety compared to the cylindrical solution. The expanding pin can be installed and retrieved easily without hammering, flame-cutting, welding and line-boring, which is recognized by the stakeholders as important regarding safety for both personnel and equipment. In addition, the stakeholders also recognize that the wear problem is considerably less with expanding pins, as also for breakage of pins and supports.

Onshore crane manufactures of tower cranes and mobile cranes seems to be less aware of the expanding pin solutions, and maybe also less aware of the problem with cylindrical pins that could have been resolved by use of expanding pins. Several reports have indicated a high level of accidents with such construction cranes.

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Conflicts of Interest: The authors declare no conflict of interest.

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