Study on Crawler Crane Accidents
Chapter 1: Introduction

1.1 Background

The number of Dangerous Occurrences involving cranes from 2011 to 2013 is as shown in Figure 1.

The number of Dangerous Occurrences over the past three years remained fairly constant. Further analysis shows that crawler cranes were the largest contributor, which accounts for 49.12% of the Dangerous Occurrences over the three-year period. With over 24,000 registered cranes in Singapore, crawler cranes make up only approximately 1,500 units or 6.87% of the entire working fleet of cranes here.

With crawler cranes making up a small proportion in the entire working fleet of cranes but being a large contributor towards Dangerous Occurrences, a study was initiated by National Crane Safety Taskforce to analyze the key contributing factors for Dangerous Occurrences involving crawler cranes and make appropriate recommendations to the various crane stakeholders for their adoption.

1.2 Legal Requirements

The key safety legislation relating to operations of cranes in workplaces are as follows:

- Workplace Safety and Health Act (Chapter 354A)
- Workplace Safety and Health (Operation of Cranes) Regulations
- Workplace Safety and Health (General Provisions) Regulations
- Workplace Safety and Health (Construction) Regulations
- Workplace Safety and Health (Shipbuilding and Ship-repairing) Regulations
- Workplace Safety and Health (Risk Management) Regulations

Relevant national standard and code of practice are as follows:

- Code of Practice on Safe Lifting Operations in Workplaces (published by the WSHC in collaboration with the Ministry of Manpower)
- CP 35 : 1996 The Selection, Care and Maintenance of Steel Wire Ropes for Hoisting
- SS 297 : 1996 Steel Wire Ropes for Hoisting

![Figure 1: Dangerous Occurrences involving cranes from 2011 to 2013](image-url)
1.3 Objectives of Study

The objectives of this study are as follows:

a) Identify key contributing factors leading to Dangerous Occurrences (collapse, failure and over-turning) of crawler cranes; and
b) Make appropriate recommendations to improve safety of crawler cranes.
Chapter 2 : Research and Analysis

2.1 Definitions

The following are the definition of the terms used in this report.

2.1.1 Crawler Crane

A self-propelled crane mounted on an undercarriage with a set of two endless tracks that revolve around wheels.

2.1.2 Dangerous Occurrence

Collapse or failure of a crane, derrick, winch, hoist, piling frame or other appliance used in raising or lowering persons or goods, or any load bearing part thereof (except breakage of chain or rope slings), or the overturning of a crane.

2.2 Fault Tree Analysis using 5M Model

The causal factors leading to Dangerous Occurrences involving crawler cranes were identified through fault tree analysis in which the 5M model, summarized in Figure 2, was applied.

![Figure 2 : Overview of fault tree analysis using 5M model approach](image)
2.3 Factors Contributing to Dangerous Occurrences involving Crawler Cranes

16 Dangerous Occurrences involving crawler cranes from 2011 to 2013 were analyzed. Figure 3 presents the distribution of factors leading to the Dangerous Occurrences.

![Figure 3: Distribution of factors leading to Dangerous Occurrence cases](image)

The analysis of the cases revealed that *machine* and *method* were significant causal factors leading to the Dangerous Occurrences compared with *man*, *material* and *medium*. Effort in terms of analysis and recommendation is therefore focused on *machine* and *method* while aspects relating to *man*, *material* and *medium* would be briefly discussed.

2.4 Analysis of Causal Factors

2.4.1 Machine

*Machine* was found to be the key causal factor leading to Dangerous Occurrences involving crawler cranes from 2011 to 2013, contributing towards 8 out of 16 or 50% of cases.

Analysis was conducted to determine the reasons of failure relating to *machine* as a causal factor.

![Figure 4: Reasons of failure relating to machine as causal factor](image)

Figure 4 indicates that there were 3 main reasons contributing towards *machine* as the key causal factor, namely failure of safety devices, such as overload, over-derrick and over-hoist limit switches, which was found to be the main culprit contributing to 4 out of 8 or 50% of cases. Wire rope failure and failure of other crane components were the remaining contributors.

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1 There may be more than one contributing factor in each analyzed case.
Failure of safety devices was largely attributed to poor maintenance regime. A maintenance regime of cranes should be comprehensive, covering safety devices of the lifting machines, to ensure they function in accordance with manufacturers’ specifications.

Due diligent in pre-operational checks of the crawler crane, including all the safety devices, by the crane operator before commencing each work shift is also crucial. This would ensure that the cranes and their safety devices are in working order. Effective safety devices could prevent catastrophe consequences in the event of any accidental unsafe manoeuvre. A feedback mechanism within the organisation for reporting of the defects should be established.

Investigations into 2 out of 8 or 25% of cases found with the luffing/hoisting wire ropes to be of unsatisfactory condition, which possibly led to the Dangerous Occurrences. The wire ropes were found to be in unsatisfactory condition over a span of length instead of being concentrated or localized.

Out of the 8 cases where machine was the causal factor, 2 of which or 25% was caused by failure of crane component. One is attributed to substandard welding repair works to boom lattice structures, not according with the required welding specifications. The other one was due to the hook block was not maintained at the recommended interval by the manufacturer or in accordance to international standards.

2.4.2 Method

Method was the causal factor contributing towards 7 out of 16 or 44% of Dangerous Occurrences involving crawler cranes.

Further analysis was carried out to determine the inappropriate methods adopted that eventually lead to the Dangerous Occurrence.

Figure 5: Reasons of failure with method as causal factor

Figure 5 shows that there were 3 main reasons contributing towards method as a causal factor, namely unsafe manoeuvre of crane, unsafe work method, overloading and poor implementation of permit-to-work system, risk assessment and safe work procedures. These findings also point towards poor development and implementation of lifting plans to ensure that all aspects for the conduct of lifting operations in a safe and sound manner have been duly considered. Unsafe manoeuvre of
cranes was found to be the main cause contributing towards 4 out of 7 or 57% of cases with method as a causal factor.

Investigation into the 5 cases showed that unsafe manoeuvres carried out by crane operators leading to Dangerous Occurrences included elevating the boom at high speeds, bypassing of safety devices to perform the lift and engaging in concurrent multiple manoeuvres such as slewing and elevating of boom. Manoeuvring the crane in an uncontrolled manner brings about instability to the crane that could lead to a collapse as shown in Figure 6. Safety devices are also installed in cranes as a measure to prevent unsafe manoeuvres from being committed and bypassing them would render them ineffective.

![Figure 6: Collapse of crawler crane involving inappropriate method of lifting](image)

The employment of an unsafe work method was observed in 1 case involving a crawler crane engaged in extracting a pile casing without consideration for skin friction induced by the soil which indirectly increases the weight of load exerted on the crane. The total weight was therefore above the maximum safe working load of the crane at the given lifting configuration.

Under the law, a permit-to-work system must be implemented at a workplace where high-risk construction, shipbuilding or ship-repairing works are being carried out. Lifting operations carried out in the construction industry involving crawler cranes are high-risk works. A thorough assessment of the risks involved and safe work procedures and lifting plan should be established before the commencement of such work activities. These were not observed in 1 out of the 6 cases categorized with method being a casual factor.

2.4.3 Man

4 out of 16 or 25% of Dangerous Occurrences involving crawler cranes was found to be caused by man as a factor.

An analysis found that all 4 cases with man as a causal factor involved unsafe operations of crawler cranes by crane operators. In 2 out of 4 or 50% of cases with man as a causal factor, crane operators left the crane unattended with the hoisting lever engaged while taking a break away from the crane.
Other cases involved the crane operator manoeuvring the crane with a large boom angle and while on sloping ground.

**Figure 7**: Collapse of crawler crane involving negligence of crane operator

2.4.4 Material

Although *material* was identified as a causal factor for 3 out of 16 or 19% of Dangerous Occurrences involving crawler cranes, the reasons leading to *material* as a causal factor have been seen to bring about catastrophic consequences.

Analysis was then performed to determine the reasons leading to *material* as a causal factor that brought about the Dangerous Occurrences.

**Figure 8**: Reasons for *material* as causal factor

Figure 8 shows that there were 2 main reasons leading to *material* being identified as the causal factor for the 3 cases with overloading taking precedence at 2 out of 3 cases or 67%. The remaining case involved the inappropriate selection of lifting gears for the load that is to be lifted.

Analysis of the cases found that crane operators overloaded the crawler cranes by bypassing the safety devices in order to lift the load to its intended location, which is further than the maximum
safe working radius of the crane for the weight of the load being lifted. Lifting a load beyond the maximum safe working radius of the crane introduces instability to the crane which could lead to collapse of the crane.

Inappropriate selection of lifting gears to perform the lift, as shown in Figure 9, was also found to be a reason which contributed to material being a causal factor. Failure of the lifting gear chosen to rig the load to the crane hook would not only introduce hazards such as falling objects but also cause adverse effects to the crane. In this case, the lifting gear failure caused the jib to back-flip due to reaction forces exerted on it at the moment when the failure occurred.

2.4.5 Medium

Medium was found to be a causal factor for 3 out of 16 or 19% of Dangerous Occurrences involving crawler cranes.

Further analysis found that all cases with medium being identified as a causal factor involved the crawler cranes operating on soft or muddy ground without steel plates such as in the case shown in Figure 10. Crane stability is significantly reduced when operating in unsuitable ground conditions or when steel plates are not laid on the ground on which the crawler cranes are operating on.
Chapter 3: Summary of Analysis

Machine, method, man, material and medium were all found to have contributed to Dangerous Occurrences involving the collapse of cranes. Machine and method were analyzed to be the causal factor of most cases. Notwithstanding this, man, material and medium still remain as important factors in ensuring safe operation of cranes.

3.1 Machine

Failure of machine refers to the malfunction of crane components such as safety devices, wire ropes and boom lattice structure. Failure of these components, especially safety devices and wire ropes, often point towards a lack of periodic maintenance and non-adherence to the maintenance regime. Safety devices such as limit switches prevent an unsafe manoeuvre which could prevent the occurrence of a collapse. Failure of boom lattice structure often occurs at welds, which was usually a result of improper repairs.

3.2 Method

Improper method adopted for the conduct of lifting operations commonly refers to unsafe crane manoeuvres and work methods. Manoeuvring the crane in an unsafe manner, which involve hoisting or lowering of load, elevating or lowering of boom and slewing at high speeds, reduces the ability of the operator’s full control of the crane. This is made worst when such manoeuvres involve multiple actions and bypassing of safety devices with the aim of completing a task in a shorter duration.

3.3 Man

The operator at the controls determines the actions to be performed by the crane. The majority of cases with man as the causal factor involve negligence of the operator. This was seen through leaving the crane engine on and operations lever engaged when leaving the crane cabin, and operating the crane in an unsafe configuration and on ground with undesirable conditions.

3.4 Material

Material being a causal factor of crane collapse refers to the load being lifted by the crane thereby causing its collapse. This commonly occurs when the weight of the load being lifted exceeds the maximum safe working load that the crane is capable of lifting at the given lifting configuration. With the bypassing of safety devices in order for the lifting operation to be carried out, an overloading situation occurs, leading to the collapse of the crane. In addition, lifting gears ensure that the load being lifted is securely held to the crane hook during the lifting operation. Failure of the lifting gears would also cause a sudden detachment of load from the crane, exerting a reaction force on the crane which could bring about catastrophic consequences to both the crane and anyone below or within the vicinity of the load being lifted.

3.5 Medium

Medium plays a critical role in ensuring crane stability as it refers to the ground on which the crane is situated or deployed on. Undesirable ground conditions such as soft or muddy ground or ground not laid with steel plates introduces instability to the crane operating on top. Centre of gravity of the crane varies during lifting operations where various crane manoeuvres are being carried out, bringing about changes to crane stability. This worsens in the presence of soft or muddy ground, leading to a collapse of crane.
Chapter 4: Areas for Improvement

The following areas for improvement were identified based on analysis of the causal factors leading to the Dangerous Occurrence cases involving the collapse of crawler cranes.

4.1 Machine

- Maintenance of crawler cranes should be carried out at regular intervals as stipulated in the maintenance regime recommended by manufacturer or internationally accepted standards. This ensures that crawler cranes used at workplaces, including their safety devices, are in good working order and functioning in a safe and sound manner as designed by the manufacturer.

- Such maintenance should be carried out by competent persons in accordance with a procedure recommended by the manufacturer. Maintenance records shall be kept up to date and indicate the type of maintenance performed on the crawler cranes.

- Load bearing parts of crawler cranes such as wire ropes should be adequately greased to ensure that they have sufficient lubrication to prevent any form of failure. Failure of such components would lead to catastrophic consequences where the load or the entire boom structure could be dislodged, creating unnecessary hazards.

- Crawler cranes sometimes require repair as part of maintenance when defects are found in their structure or components. Repair works should only be carried out by an approved crane contractor to carry out repair on the respective models of cranes. This ensures that the repair work is carried out in accordance to manufacturer’s specifications so that the integrity of the crawler crane, after the repairs have been completed, is not compromised.

4.2 Method

- Manoeuvring of crawler cranes should always be done with due caution regardless of the type of manoeuvres being carried out. Crane operators should always ensure that they are able to maintain full control the crane. In order for this to be ensured, crane operators should only operate the cranes at a safe speed. Safety during lifting operations should never be compromised over limitation in time to complete a lifting activity.

- Lifting operations involving crawler cranes are classified as high-risk work activities. A permit-to-work system should be implemented at the workplace covering such activities while ensuring that the necessary safety precautions are taken and enforced when such activities are being conducted. Persons involved in the conduct of such activities, such as those comprising the lifting team, should also be well informed of the hazards they are exposed to and the precautions they should take to carry out the work in a safe and sound manner.

- A detailed method statement should be prepared before the conduct of lifting operations. The method statement should be prepared by a competent person who is familiar with the work tasks and steps involved in the lifting operations. This is to ensure that potential hazards and risks are considered during the conduct of each step and all reasonably practicable control measures are implemented to mitigate the risks identified to as low as reasonably practicable.

- Lifting plans aid the lifting team in planning for the conduct of lifting operations in a safe and sound manner. Lifting plans should therefore be prepared with due diligence with consideration of all factors affecting the lifting operations such as load, lifting machine, lifting gears, lifting team, means of communication, physical and environmental conditions and appropriate rigging methods to be employed. An appropriate safety factor should also be considered when selecting
suitable lifting machines, appliances and gears for use to conduct lifting operations. Lifting plans should then be audited by a competent person for relevance and sufficiency before they are implemented.

4.3 Man

- The analysis of Dangerous Occurrences involving crawler cranes found that the crane operator, being the person at the helm of the lifting machine, was usually the person involved where man was identified as the causal factor leading to the incident. Being the one in control of the lifting machine, it is paramount that the crane operator does not engage in any unsafe act or manoeuvre which compromises the safety of the lifting operations which would in turn bring about hazards and risks to persons in the vicinity of the machine. The crane operator should carry out his duties with due diligence and conform to any rules of safe operations of cranes. They must not bypass safety devices such as limit switches and warning lights and alarms. Regular audit checks should also be initiated by the Occupier to ensure that persons in the lifting team do not infringe any rules for safe conduct of lifting operations.

- Crane operators should carry out pre-operational checks on the crane with due diligence before the start of every work shift. The results from such pre-operational checks should be recorded in a checklist which is to be kept as a record. The lifting supervisor should also ensure that any fault with the crane found during the conduct of such pre-operational checks is duly reported by the crane operator and necessary rectification action carried out thereafter.

- Man, in particular the crane operator, should not solely rely on safety devices, such as limit switches, to prevent any unsafe manoeuvre of crawler cranes. Safety devices are installed in cranes as a final measure or barrier to prevent such unsafe manoeuvres from being carried out. Sole reliance on safety devices could increase the chances of undesirable outcomes should such safety devices fail. The following measures could be taken to remind crane operators not to rely solely on safety devices to determine the lifting limits of the crane.
  
  a. Conduct of structured training to raise competence of crane operators in determining lifting capacity of crawler cranes with at various lifting configurations; and
  
  b. General safety awareness briefings and reminders to crane operators during the daily toolbox meeting before the start of every work shift.

- Development of an Appointed Persons (AP) and Lifting Engineers (LE) Course to provide relevant and structured training to persons involved in lifting operations. The course could focus on the development and execution of a comprehensive lifting plan to suit to the actual lifting operations being conducted.

- Development of technical courses by crane manufacturers to equip mechanics involved in crane maintenance and repair with the necessary competence to carry out such tasks in accordance with manufacturer’s recommendations and internationally recognised standards.
4.4 Material

- Proper selection of lifting machines play an important role in ensuring that loads can be lifted from origin to intended destination safely. Selecting a lifting machine with a sufficient lifting capacity would reduce the probability of crane operators stretching the limits of crawler cranes to complete the lifting assignment, which could be seen as a form of undesirable act.
- Proper selection of lifting gears is also another critical area of consideration. Improper selection of lifting gears would lead to a compromise in integrity of lifting gears during the lifting operation. As there are no safety devices installed with lifting gears, warning signs indicating their failure during lifting operations are not as obvious. Failure of lifting gears also bring about catastrophic consequences as this poses hazards involving falling objects, compromising the safety of persons, such as the lifting team, who are in the vicinity of the crawler crane.

4.5 Medium

- Ground conditions on which crawler cranes are deployed should be thoroughly assessed before the deployment of the crane and commencement of lifting operations. Soft ground reduces the stability of cranes operating on the surface where a sudden depression caused by the various crane manoeuvres could destabilize the crane to an extent to cause a collapse.
- Measures such as ensuring that the maximum ground bearing pressure is above the maximum force exerted by the crawler crane during the planned lifting operations, with consideration of the heaviest load being lifted, should be carried out while safe crane access should be ensured.
- Crawler cranes should be deployed to operate on flat ground. Ground flatness should be determined before their deployment and commencement of operations to enhance their stability during operations.
Chapter 5 : Recommendations by National Crane Safety Taskforce

With the aim of enhancing safe use and operations of crawler cranes at workplaces, the National Crane Safety Taskforce has made several recommendations. The Taskforce will collaborate with the Workplace Safety and Health (WSH) Council and the Ministry of Manpower (MOM) to roll out joint initiatives to raise the standards for crane safety in the industry.

5.1 Enhancement of Maintenance Regime  

Crane owners should develop comprehensive inspection and maintenance checklists for use by the respective competent persons to assist them in carrying out a thorough inspection and maintenance of crawler cranes. These checklists shall include detailed checks not only on the various safety devices but also on crane components such as wire ropes and boom structure. References should be made to recognised standards such as the Singapore Standard SS536:2008 Code of Practice for the Safe Use of Mobile Cranes and the crane maintenance manual issued by the manufacturer when developing the checklists. The syllabus of the AP/LE Course should also cover the development of a comprehensive maintenance checklist.

Observations also showed that the frequency for maintenance of crawler cranes varies between crane owners from once monthly to once half-yearly. The Taskforce recommends that the frequency for maintenance of crawler cranes be standardized to at least once monthly. Regular and frequent maintenance ensures that crawler cranes are functioning in accordance to manufacturer’s specifications and requirements, thereby reducing the probably for the occurrence of component failures which in turn mitigates the risks brought about by such failures.

5.2 Establishment and Implementation of Lifting Plan Adequate for its Purpose  

The lifting plan is an important document which serves the purpose of ensuring that lifting operations are well planned. A lifting plan can only serve its purpose effectively when all the necessary parameters are included. The Taskforce, with the WSH Council and MOM, will launch a set of guidelines for preparing lifting plans for lifting operations in workplaces to assist stakeholders in developing a comprehensive lifting plan which considers and covers all relevant parameters before the actual lifting operation is being executed. These guidelines shall be used in conjunction with the Code of Practice for Safe Lifting Operations in Workplaces.

Persons preparing and reviewing the lifting plans are encouraged to attend the Appointed Persons for Lifting Operations Course which is currently being developed. The course equips Appointed Persons involved in Lifting Operations with knowledge and skills such as selection of lifting equipment, employment of suitable rigging methods, and developing and implementing a lifting plan to conduct lifting operations in a safe and sound manner. Lifting plans should also be audited both on a regular basis and before the commencement of lifting operations. The auditing process ensures that the lifting plan is adequate for its purpose and that the appropriate method is adopted for the lifting operations to be carried out in a safe and sound manner.

5.3 Ensuring Competency of Persons Involved in Lifting Operations  

Persons involved in lifting operations not only include the lifting team which comprises of the crane operator, lifting supervisor, rigger and signalman but also personnel such as the Safety Assessor for the workplace who assesses and ensure that the permit-to-work system for lifting operations is well implemented. Crane operators should be adequately familiarised with the operations of the particular model of crawler crane that he/she has been assigned to operate. Crane operators should
also ensure that they operate the crawler cranes in a manner such that they are able to maintain full control of the crane manoeuvres at all times and not perform any action to stretch the capacity of the crawler crane beyond its safe working limits. Lifting Supervisors, as the appointment suggests, should play a more proactive role to supervise all lifting operations to ensure that they are being carried out in accordance with safe and sound practice.

The Taskforce recommends that Safety Assessors should possess the necessary knowledge and skills before being appointed as an Assessor for the permit-to-work system for lifting operations. The Assessor shall demonstrate the competence to assess the lifting plan to ensure that it is prepared in accordance to the relevant standards and is effective for the lifting operations being conducted, identify associated risks and ensure that relevant measures are implemented to mitigate such risks.

The Taskforce also recommends that additional structured training courses and workshops such as the AP/LE Course be conducted for persons involved in lifting operations to provide them with refreshers on skills required to ensure that lifting operations are carried out in a safe and sound manner. Such courses and workshops could cover in depth or refresher topics such as methods to ensure suitable ground conditions for crawler cranes to operate, safe manoeuvre of crawler cranes and good rigging practices.

The development of the AP/LE Course could introduce an additional appointment to the lifting team. The appointment of a Lifting Engineer, on top of the Lifting Supervisor, could play the role of an auditor of lifting plans for both routine and complex lifts. The role of this specialist position is to ensure that detailed preparations with all relevant aspects of the lifting operation to be carried out are duly considered so that the lifting operation would be carried out in a safe and sound manner.

With crane operators playing a critical role in the safe operations of crawler cranes, the Taskforce further recommends that a Crane Operator Registry be developed. This registry would contain full records of all registered crane operators such as classes of crane license obtained, years of crane operation experience, work experience such as projects involved and types of cranes operated, trainings undergone and past penalties accumulated. A demerit point system could then be introduced for any contravention committed by crane operators to safe and sound practice of crane operation. The Crane Operator Registry would be useful for employers to determine the pool of operators who are best suited for the job by considering their prior work experience in the specific type of lifting operations which would be carried out at the worksite before they are engaged.

5.4 Establishment of System to Track Unsafe Crane Manoeuvres [Material]

As unsafe manoeuvres carried out by crawler cranes, especially pertaining to overloading, were found to be a causal factor leading to their collapse, the Taskforce recommends that a system be established to track crawler crane manoeuvres, especially when being operated in an unsafe manner. A data logger, compatible with the crane functions, could be installed in cranes where manoeuvres beyond the working limits of the cranes are being captured. Details of such unsafe manoeuvres would be made available for incident investigation or even surveillance and behavioural study purposes.
5.5 Ensuring Suitable Working Platform [Medium]

The working platform i.e. ground on which crawler cranes are operating should be certified safe for the configuration of the crane and maximum load that would be lifted during the entire course of lifting operations. Accurate details of the configuration and specification of the crawler crane should be provided by the crane manufacturer while details of the load should be provided by the lifting team involved in developing of the lifting plan before appropriate calculations could be prepared and certified by a Professional Engineer (Civil). In addition, the Taskforce recommends that adequate steel plates should be provided over crane access and operation areas to ensure crane stability during travel and operations.
Chapter 6: Conclusion

This report presents an overview of the analysis of crane-related Dangerous Occurrences which took place over a three-year period. The analysis described the various causal factors leading to the Dangerous Occurrence case with *machine, method and man* found to be the main areas of concern.

Through the observations, crane safety can definitely be improved. The recommendations presented by the Taskforce in Chapter 5 are derived from analysis of the causal factors and reasons that led to the Dangerous Occurrence cases. The Taskforce will target the causal factors and further look into areas which could be enhanced to mitigate the likelihood of a similar occurrence. This could include, for example, working with crane owners to jointly develop inspection and maintenance regimes and checklists and developing training courses to equip persons involved in lifting operations with enhanced skills to enable them to conduct these activities in a safe and sound manner.

Acknowledgements

This set of recommendations was developed by the following industry-led workgroup formed under the WSH Council-led National Crane Safety Taskforce. Members of the workgroup dedicated their time in their individual capacity to make this set of recommendations possible. Representatives from the Ministry of Manpower and WSH Council were actively involved and provided the necessary support in the development of the recommendations.

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