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Ship transport to Japan – What can be learned from the Tsunami of 11th March 2011?

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Abstract

The Japanese tsunami of 11th of March 2011 powerfully demonstrated the devastating effects of such events on the transport and general infrastructure of the country as well (of course) as the well documented consequences for the Nuclear Power Station at Fukushima Daiichi. As a responsible operator, this caused INS to ask the question 'what if' and review our subsidiary Pacific Nuclear Transport Limited's (PNTL's) operations in Japanese ports and waters (and any other earthquake prone regions). This paper will review the potential consequences of a tsunami during such operations and describe the measures taken by INS and PNTL to ensure as far as practicable the safety of the ship, personnel and cargo. The paper will also consider the likely consequences to the cargo should a tsunami hit at the most inopportune time during transport operations and demonstrate that the consequences are bounded by the IAEA accident conditions.

Introduction

Following the earthquake and tsunami in Eastern Japan on 11th March 2011, INS undertook a review of the operational arrangements for PNTL shipments to Japan. PNTL vessels have extensive emergency procedures although there were no specific procedures for tsunami. It was common knowledge among ships' staff, however, that the ship would be safest in deep water. Indeed in the past, Pacific Sandpiper had ridden a tsunami wave when in deep water with no adverse effects. As a result of the review, it was recognised that we needed to consider in detail the most likely potential scenarios and introduce written procedures. The resulting new emergency response procedures for earthquakes and tsunamis are contained in the Shipboard Marine Emergency Plan (SMEP), with preparatory steps and general information in the ship Operations Handbook.

In carrying out the review, one other significant issue was identified – What are the cargo implications if a tsunami leaves a ship stranded on dry land (or at least where cooling systems cannot be operated)? This issue is the subject of a separate paper [1] which shows that whilst the flask will suffer some degradation, its condition is bounded by the IAEA accident criteria. As this is the subject of a separate paper, it is not considered in any further detail here.

Review

In carrying out the review, it was determined that there were three related but separate 'assets' to be protected:

Ship – if the ship can be protected from all but superficial damage, then this will provide protection to both the crew and cargo.
Crew – potentially most the vulnerable and safety of life is a primary consideration. For example, with a short warning time, the crew will not be put at risk by deploying to open decks to handle mooring lines. Instead they will seek refuge within the vessel structure.
Cargo – the robust nature of the flasks means they are likely to take care of themselves and are therefore last in the 'priority order'. It is however necessary to consider what might happen to the flasks in the ship, being lifted or on the quayside to determine the likely outcome of the incident and the response measures required.

There are then a number of scenarios which can be considered. These are a combination of a number of (largely) independent factors which can occur in any combination in a tsunami event. For reference these are laid out in table 1 and each factor is considered below.

Factor	**Possible 'states' at time of incident**			
Ship location	Tied up in loading / unloading port	In shallow water	In deep water	In bunker port (no cargo)
Cargo	Tied down in ship	In ship but not secured	On crane	On quayside
Hatch covers	Closed	Open		
Timescale	Very short warning	Intermediate warning	Long warning	
Tsunami warning	Tsunami warning issued	Tsunami advisory issued	Earthquake without tsunami warning or advisory	

Table 1: Scenario factors

Ship location

When the tsunami warning is received, there are a number of possibilities for the position of the vessel. Ideally the vessel should aim to reach deep water, however its location when the warning is received will have an impact of whether (and how quickly) it can reach a position of safety. If the vessel is in port or shallow water, then it should proceed as quickly as possible to deep water. Clearly if it is tied up in port then there will be some delay whilst the mooring ropes are removed and the vessel gets underway (see below for preparatory steps and departure actions). Once the vessel is in deep water, the only remaining action is to maintain vigilance and turn into any observed wave.

Cargo

The cargo is clearly most at risk during loading and unloading operations. At other times it will be protected by the vessel. Depending on whether the flask is currently being lifted, the reaction time may be longer as the flask will need to be lifted clear before the vessel can depart. Clearly coordination between the ship and the cargo handling operators needs to be clearly defined in advance so that there are no delays in deciding what to do.

Consideration was also given as to whether it was necessary for the flasks to be fully bolted down. Whilst it is clearly preferable to have the cargo fully secure, delaying departure whilst the securing bolts are fitted is likely to result in an increased overall risk of the ship being hit by a tsunami in port or shallow waters. It was therefore decided that the ship should depart even if the flask is not secured. The risks arising from this will be minimised by only having one flask unbolted at any time and also by refitting the bolts during departure if this can be carried out without putting personnel at risk.

Hatch covers

The hatch covers of the ship are lifted by the shore crane and at the time of any warning may be either open or closed. Replacing the cover takes a significant amount of time and this needs to be balanced against the risk of departing without the covers in place. The PNTL ships however are designed to remain afloat with all holds flooded and therefore it is safer to put to sea without the hatch covers and risk flooding of a hold rather than delaying and being caught in port or shallow water. The risk can be minimised by only opening one hatch at a time such that a maximum of one hold could be flooded by a tsunami wave.

Timescale

The length of time from the warning being received until the expected arrival of the tsunami is clearly a crucial factor in decision making. For example in the event of an earthquake in California triggering a tsunami warning in Japan, there is likely to be a number of hours before the tsunami arrives. At the other end of the spectrum, there may only be minutes which would mean there was insufficient time for the ship to depart port and all efforts would need to focus on getting the ship's crew and shore staff to a position of safety on board or ashore.

Tsunami warning

There are different types of tsunami warning depending on the size of the expected wave (Tsunami advisory – wave height predicted to be about 0.5m; Tsunami Warning {Tsunami} – wave height predicted to be up to 2m; Tsunami warning {Major Tsunami} – wave height predicted to be 3m or more). Furthermore, it is possible for an earthquake to occur without a tsunami warning being issued. The response needs to take account of these variations.

Tsunami Arrangements

From table 1, a large number of potential scenarios can be derived considering each of the factors in each of its possible states. As far as practicable generic arrangements were derived to cover all of these situations. It was also recognised that the greatest risk was in the event of a tsunami occurring whilst a vessel is in port. The next greatest risk was of a tsunami hitting the ship whilst it is in shallow water near the shore.

In any scenario, speed of response is likely to be a critical issue. It is therefore necessary to ensure good prior coordination between the vessel and shore to be sure everyone knows what is required and the appropriate communications routes. This in turn helps to ensure that delays in responding are kept to an absolute minimum.

Preparation

Prior to entering the load / discharge port, there are a number of factors which can be agreed between the vessel and shore to ensure the fastest possible evacuation should that be necessary. Typical arrangements at the time of a port call would include the following:

- Subject to port constraints including crane access to the cargo, the vessel should be berthed facing out of the port.
- One of the main determining factors in how speedily a departure from port can be made is how long it takes to get the engines up and running. At one extreme, with engines totally shut down and cold, it could take 30 to 60 minutes to start them and be ready to depart. The other end of the spectrum would be to have the engines running throughout the port call, however this would unnecessarily burn fuel and long term running of the engines in an idle condition has the potential to cause damage. Typically this could include premature wear as well as the risk of partly burned fuel deposits in the engine and exhaust systems. The best compromise was therefore considered to be retaining the engines on 5 minutes notice. This delay was considered to be commensurate with other necessary preparations for departure such as deploying the crew to the mooring stations and commencing the un-mooring operations.
- If possible, hatch covers and tween decks are to be landed ashore (however in practice, this is unlikely to be possible due to space and crane reach

constraints). If these items are stacked on board, they should be secured to avoid movement if the ship does need to depart without replacing them.

- Only one hold to be open at any time.
- Mooring ropes to be placed on a bight wherever possible. That is the rope should be lead out from the ship, round the bollard on the quay and back to the ship where the end is then secured. This means that the mooring rope can be let go from the ship without the need for someone ashore to remove it from the bollard. As a last resort means of un-mooring, axes are also placed at the mooring stations to allow the mooring ropes to be cut.
- Clear arrangements need to be made for communication of any warning to the vessel. This is particularly the case in Japan where the warning in Japanese is unlikely to be understood. This function is performed by the shipping agent who remains onboard throughout the port call.
- There is also the need for a protocol on lifting between the port and the ship. In most cases, the arrangement will be that where the flask (or tween deck or hatch cover) is attached to the crane when the warning is received then it will be lifted clear. As soon as the lifted item is clear, the ship will commence its departure.
- Finally, there needs to be an understanding that port staff may need to remain on board if they cannot evacuate quickly enough when the warning is given.

On receiving warning

Firstly the Captain needs to assess the nature of the warning. If the warning is very short, then it may not be possible to depart. In this case, the watertight doors will be closed and everyone will remain in internal areas and brace themselves for the likely violent motion when the tsunami strikes (noting there may be a succession of waves). Consideration has been given to putting out extra mooring ropes, however as this scenario only arises when the warning time is very short, there will not be time to deploy additional lines without putting personnel at considerable risk on open decks / quayside. Furthermore with the forces involved in a tsunami (especially on a ship which is naturally buoyant), it is highly unlikely that sufficient lines could be deployed to restrain the vessel.

If there is a long time before the tsunami is expected (for example the cause is an earthquake on the other side of the Pacific) then the vessel will make ready for a normal departure with all hatch covers replaced and normal departure checklists and procedures fully used.

For intermediate lengths of warning where a fast departure is required, the following sequence will be initiated:

- Engines are to be started and personnel deployed to the mooring decks.
- Any items attached to crane (flask, tween deck, hatch cover) lifted clear.
- As many shore staff as possible to leave the vessel for a safe location ashore.
- Gangway removed (at this point, some shore staff may need to remain onboard).
- Mooring ropes released (cutting by axe only as a last resort – tension to be released first).

- Ship departs even if the hatch cover is open and if tween decks or flasks are not secured.

The attached flowchart (figure 1) provides a pictorial explanation of these procedures.

If the warning is received as the vessel approaches the port, then the Captain will wherever possible turn around and head back into deep water. This would also be the case if the vessel was in shallow coastal waters when the warning was received.

Generally the flask safety will be ensured by the robust nature type B package and therefore the Master's primary concern will be the safety of the vessel and personnel on board. It is recognised that ships crew may be left ashore if they are unable to get back on board before the vessel sails. These individuals will then need to seek shelter ashore with other shore personnel. Similarly shore personnel may remain on board as the vessel departs. The detailed arrangements take account of both of these scenarios and the need to ensure as far as possible the safety of all personnel.

Other Considerations

In carrying out these reviews, a number of other considerations and scenarios have emerged. Consideration has been given to other natural disasters as well as events such as wide spread epidemics or civil unrest. Whilst each of these is different in nature, the effects on the shipment manifest themselves in similar ways.

Port facilities unavailable

Short term disruption (e.g. due to a storm) is not a significant concern and can be dealt with by means of a short delay. Longer unavailability is however of more concern and requires alternative ports to be considered. For the type of heavy flasks used for the transport of spent fuel, HLW and MOX, there are limited ports with the necessary infrastructure to receive the cargo. In Japan however, most Utility reactor sites have a dedicated port with suitable craneage and therefore should the destination port be out of service, there will be other suitable ports available elsewhere in Japan.

Ship stranded aground

In the case that a tsunami causes a vessel to be washed ashore and stranded, it will no longer be possible to cool the holds (the cooling system will not operate without sea water for the heat exchanger and even if cooling water can be provided, it may not be possible to run the system if the ship is not sufficiently upright).

Initial consideration of this condition is that the damage to the flask (primarily possible melting / degradation of the shielding resin) is unlikely to be any more significant than the fire damage case (where it is assumed that all the resin melts or is burned off). It is therefore to be expected that the flask condition will remain within the accident criteria. Further analysis of the temperature conditions in the hold has been carried out and is the subject of a separate paper [1].

Crane incapacitated or damaged by earthquake or similar

If the port crane is incapacitated (or worse collapses on the vessel) due to a natural disaster whilst unloading, then the vessel will be prevented from leaving the port until the organisation responsible for lifting makes alternate arrangements. This scenario is mitigated by the robust construction of the cranes used for this type of transport. In Japan specifically, the operators are taking steps to ensure that alternate sources of power are available. It is not considered practical to further mitigate against this scenario. In any case, even in the event of a crane failing and dropping the load or collapsing on to a flask, it is highly unlikely this will result in damage in excess of the accident conditions envisaged by the IAEA regulations. In any credible scenario, the fact that the vessel is floating on water provides for significant energy absorption in the event of an impact.

Earthquake or Tsunami whilst in bunker port

During a typical round-trip voyage to Japan, the PNTL vessel will spend several weeks in Japan. Most of this time is spent in a so-called ‘bunker port’ which is typically a normal commercial port where the vessel can remain at a quay and where any necessary maintenance, loading of stores and refuelling can take place. The tsunami procedures have been developed to address the dangers from earthquakes and tsunamis whilst in a delivery port and require engines to be maintained at 5 minute readiness which in turn requires permanent manning of the engine room. Such arrangements are not practical in a bunker port and therefore alternate considerations apply.

PNTL’s minimum manning requirement ensures there are always sufficient personnel on board to take the vessel to sea in an emergency (already implemented for typhoon warnings).

The bunker ports typically used (Kobe and Moji) are in areas where the risk from tsunami has been assessed by the Japanese Authorities to be low.

In the event of a warning being received, there is no cargo to consider and therefore the Master’s first concern will be the safety of ship’s crew. Depending on the warning received, the Master can therefore decide to depart, evacuate to high ground / tsunami shelter building or to close down watertight doors and prepare for the tsunami wave to hit the vessel.

Flask Impacts

If a flask has been unloaded from the vessel when a tsunami strikes, there are two possible scenarios for damage:

- the flask is moved by the wave and collides with a fixed obstruction
- an object being propelled by the wave strikes the flask.

In both of the above cases, it must be noted that the impact is unlikely to be equivalent to the impact with an unyielding surface. Further, in shallow water (e.g. ports) the wave speed of a tsunami is much lower than in deep water (it is the shoaling effect that causes the tsunami wave height to increase). Typical speeds for a tsunami in shallow water are between 36 km/h (10m depth) and 79 km/h (50m depth) [2]. By comparison, the speed of impact in a 9m drop test is 48km/h.

The conclusion of this simple analysis is that the damage to a flask from impacts is most likely to be bounded by the IAEA impact drop tests.

Conclusions

Revised arrangements have been implemented through changes to the Standard Operating Procedures and Emergency Procedures to address the hazards associated with earthquakes and tsunamis during port calls in Japan. These revised arrangements are intended to protect the ship and personnel in the event of earthquakes or tsunamis during port operations. Protecting the ship in general will also protect the cargo; however it has also been shown that the robust nature of the type B flasks used to transport spent fuel, HLW and MOX give a significant degree of protection in the accident scenarios which can be reasonably expected to arise from such events.

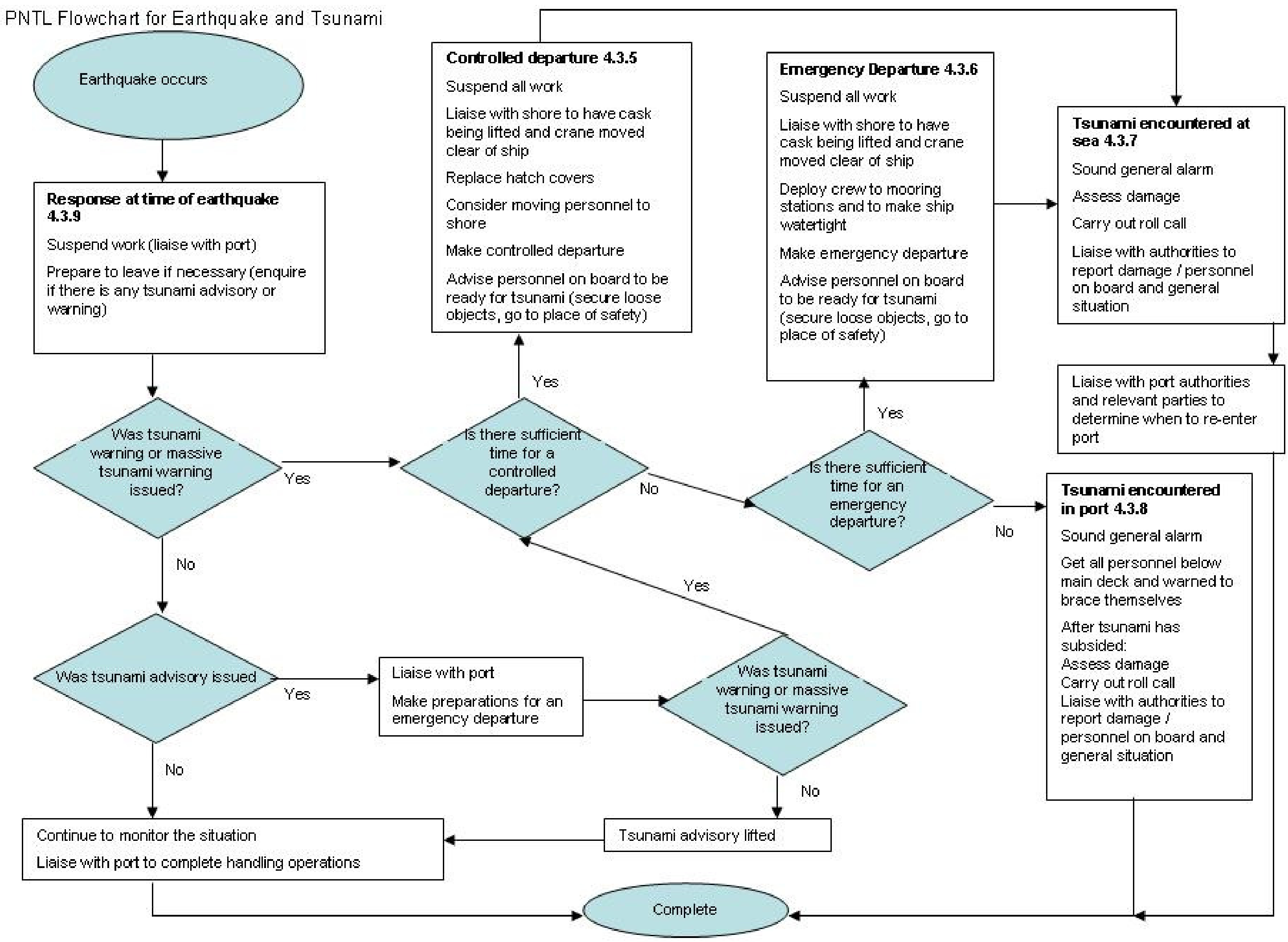

Figure 1: PNTL Flowchart for Earthquake and Tsunami Response

References

1 Darrell Egarr, MMI Engineering Ltd et al. (2012) RAM 48 Thermal Assessment of TN28VT Flasks carrying Vitrified Residue
2 Hyper Physics, Georgia State University (http://hyperphysics.phy-astr.gsu.edu/hbase/waves/tsunami.html)

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