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ABSTRACT

This paper compares the French and Japanese scour risk assessment procedures, namely the machine learning (ML) model from the French National Railway Company (SNCF) and the scoring table proposed by the Railway Technical Research Institute (RTRI) in Japan. To demonstrate how to use the guidelines and make a comparison, they are applied to two bridges located in Japan and France respectively. In general, both guidelines aim to help screen high scour risk structures in an effective way. However, due to the different modes of inspection and hydrologic conditions, the parameters required in each approach are quite different. The two approaches are detailly compared and future directions for improvement are proposed. Results of this paper could be served as an insightful reference to institutes or countries who want to develop their own guidelines.

1. INTRODUCTION

Transport agencies take responsibility to ensure the security of the transport network. Bridges, as crucial points of connection in the network, are exposed to natural hazards like flooding.

In Japan, flood, which is often induced by storms, typhoons or heavy rain, is identified as the primary natural hazard to cause bridge damage (Abé et al., 2014). Bridge scour often occurs after flood events and it has been recognized as the foremost cause of bridge failure worldwide (Dikanski et al., 2018).

The French National Railway Company (SNCF) estimates that there are roughly 10,000 bridges and retaining walls crossing or adjacent to waterways in the French rail network. Most of them aged more than 120 years old (SNCF, 2020). Similarly to France, Japan also possesses a large number of historical railway bridges. Scour has recently become a serious issue in both two countries due to the increased frequency and intensity of extreme weather events (Takayanagi et al., 2019).

Managing a large number of assets with a constrained budget, the transport agencies should have practical guidelines to evaluate the risk of structures, in order to plan and prioritise the maintenance work. To date, various guidelines have been developed for the management of bridges under flood hazards (Abé et al., 2014; Arneson et al., 2012; HR Wallingford, 1992).

This paper compares two scour risk assessment procedures adopted in Japan and France respectively. The Japanese and French procedures are briefly introduced firstly. Later, they are applied to two bridges (one in Japan and one in France) as case studies. Similarities and differences between the two guidelines are compared and the future directions for improvement are discussed in the end.

2. SCOUR RISK ASSESSMENT IN JAPAN AND FRANCE

Both Japan and France have a large number of historical assets in the rail network. To ensure the safety of passengers, regular inspection – maintenance is necessary for railway infrastructure. Engineers or inspectors need to conduct several visual inspections each day. A practical yet effective method must be proposed to them to screen high risk structures. This section presents briefly two practical guidelines used in Japan and France for scour risk assessment.

2.1 Scoring table in Japan

Proposed by the Railway Technical Research Institute (RTRI), the Japan Railways Groups (JR) employed a scoring table (Takayanagi et al., 2018) to assess the scour risk of railway bridges.

In this approach, factors related to scour risk are divided into three categories: environmental condition of river (four items), structural conditions of bridge pier (six items), and protection conditions of bridge pier (five items). The evaluation items in each category are considered having an important impact on scour risk assessment and they are chosen on the basis of past disasters happened in Japan. It should be noted that many parameters used in empirical formulas for calculating scour depth are reflected in this approach. Moreover, types of scour countermeasures as well as the damage level of scour countermeasures have been taken into account.

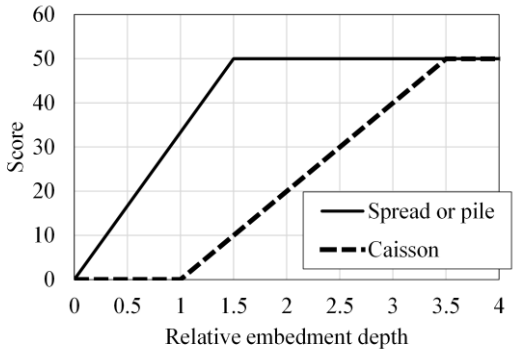
Figure 1 shows the scoring table used in Japan. The importance of each evaluation item to the final scour risk is quantified by the score shown in the column “Score”. Detailed explanations of several evaluation items (e.g., “Constriction of rived width”, “Bridge pier

location relative to river bend") may refer to the work of Takayanagi et al., (2018). The score of the evaluation item "Relative embedment depth" is calculated based on Figure 2.

Evaluation item		Choice	Score
Environmental condition of river			
Topographical land form		Plain	10
		Valley plain	10
		Alluvial fan	0
		Mountainous area	5
Constriction of river width		Absent	15
		Present	0
Riverbed material		Sand	10
		Gravel	0
		Exposed rock or boulder	10
Overall rivedbed degradation		Present	0
		Absent	10
Protection conditions of bridge pier			
Absent			0
Unknown			0
Deterioration of basket foundation		Present	0
		Absent	5
		Unknown	0
Block footing protection	Deterioration	Absent	20
		Partial	5
		Overall or washed away	*
		Unknown	0
	Connection	Present	5
Expansion of footing	Relative embedment depth	Top of protection work < Riverbed	20
		Bottom of protection work < Riverbed < Top of protection work	10
		Riverbed < Bottom of protection work	*
	Deterioration	Present	*
		Unknown	0

Evaluation item		Choice	Score
Structural conditions of bridge pier			
Bridge pier location relative to river bed		Straight river or inside of river bend	15
		Outside of river bend	0
Bridge pier location relative to floodplain		In river flow	5
		Floodplain without revetment	10
		Floodplain with revetment	25
		Floodplain without revetment and adjacent to river flow	0
		Floodplian with revetment and adjacent to river flow	15
Downstream drop structure		Absent	20
	Height	Up to 1m	5
		1-2m	0
		More than 2m	0
	Deterioration	Present	*
	Construction range	Only a part of river course	*
Relative embedment depth		Spread foundation or pile foundation	
		Caisson foundation	
Variation of embedment depth		Increase or decrease in depth by more than 1.5m in comparison with that in the previous inspection	*
Bedrock contact		Absent	0
		Probable	15
		Present	30

Figure 1 Scoring table used for Japanese railway bridges (Takayanagi et al., 2019)



Relative embedment depth = L / B
(L: Embedment depth, B: Bridge pier width)

Spread or pile foundation
Score = $50 / 1.5 \times L / B$
(Embedment depth of pile foundation shall be the depth between footing bottom and riverbed)

Caisson foundation
Score = $20 \times L / B - 20$

Figure 2 Relationship between relative embedment depth and score (Takayanagi et al., 2019)

The final bridge score is calculated by summarizing the score of evaluation items shown in Figure 1. If the final score is less than 110, a detailed inspection and more complex studies shall then be needed. It's noteworthy that several choices in evaluation items with a "*" mark are considered strongly related to a potential scouring disaster. Therefore, if one of these choices is included in the investigated bridge pier, it is regarded as high risk and needs more detailed inspection immediately, regardless of the sum of scores.

The score of each evaluation item and the threshold value 110 were calibrated on historic survey data of 77 bridge piers in Japan. The same 77 bridge piers were regarded as high risk by railway engineers without using scoring table. In addition, it has been tested and confirmed that the results from scoring table and railway engineers are generally in agreement with each other.

2.2 ML model in France

Due to the complexity and multidisciplinary nature of scour, an extreme gradient algorithm (XGBoost) based machine learning model (Wang et al., 2022) was adopted at SNCF for scour risk assessment. The advantage by adopting a data-driven approach is that it can discover patterns in data which are not apparent to human.

The French ML model was trained by using data provided by the French National Railway Company (SNCF). This database comprises 208 measurements (208 bridge piers) at 75 bridges. Figure 3 illustrates examples of bridges included in the dataset. To cover a wide range of topography and hydraulic conditions in this dataset, 16 out of 19 SNCF regions' (see Figure 3) bridges were included.

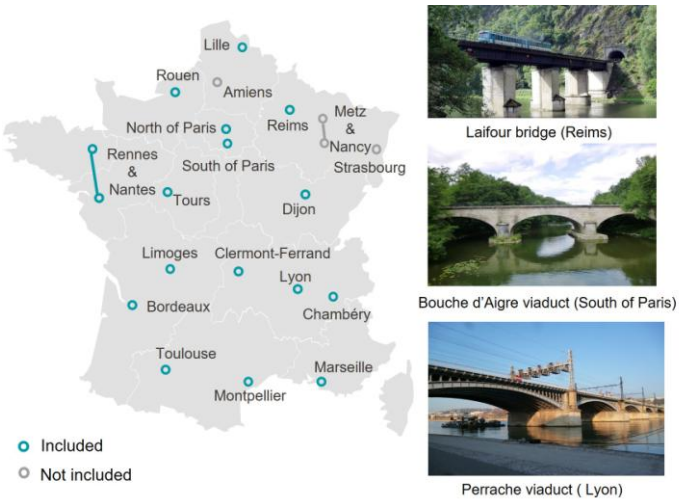


Figure 3 Examples of bridges included in the SNCF data set for ML model construction. (Wang et al., 2022)

Input variables in this ML model comprise information regarding bridge characteristics, surrounding environment, history, and observed damages in the field, and there are 18

parameters in total. Table 1 shows one example in the dataset. The output of ML model is scour risk around the bridge pier. It is divided into two classes: high scour risk and low scour risk.

Table 1 Example of input data in the ML model

Variable	Value	Variable	Value
Flow type	Fluvial	Existence of foundation scour countermeasures	Yes
Slope of riverbed (%)	0.15	Scour history	Yes
Flood flow(m3/s)	302.18	Flood history	No
Width of valley/width of high flow channel	8.48	Susceptible of scour	No
Topography	Plain	Channel rating	Fair
Flow sinuosity	Sinuous	Riverbank rating	Good
Riverbed material	Rock	Existence of dislocation or deformation	No
Pier shape	Rectangular	Existence of local scour	No
Foundation type	Caisson	Rating of other damages	Good

To build the ML classifier, 70% data were used for training and the rest for testing. In the end, compared with other ML algorithms, the XGBoost algorithm achieves high accuracy (0.959/0.938), precision (0.970/0.961), recall (0.974/0.956) and low false positive rate (0.085/0.114) for training and test sets respectively. Details about the French ML model are presented in the work of Wang et al. (2022).

3. SITE SELECTIONS

To compare the French and Japanese guidelines, they are applied to two bridges located in France and Japan respectively. Figure 4 shows the photos of bridges and the piers to be tested.

Richebout bridge (Figure 4a) is located in Butry-sur-Oise, a city in the north of Paris in France. It crosses the Oise River which flows into the Seine River. Richebout bridge is used for rail and road circulations. The bridge was constructed in 1915 and then reconstructed after World War II. It consists of three spans with a steel deck. The two masonry bridge piers are in river channel. According to the archives, the bridge pier foundations were reinforced in 1981. The velocity of river is measured between 0.3 to 0.5 m/s during inspection, and the slope of riverbed is around 0.01%.

Ookawa bridge (Figure 4b) is located in Aizu-wakamatsu, Fukushima prefecture in the northeast of Japan. The bridge is in a scenic railway line operated by East Japan Railway Company (JR East). It crosses the Agano River which meets Nippashi River, and Tadami River and falls into the Sea of Japan. Ookawa bridge consists of 22 bridge spans with a steel deck and the total span is 439m. Ookawa is built on caisson foundations, and the bridge pier is on masonry. The pier's width is approximately 3 m. In 2015, the river level rose significantly

due to the heavy rain caused by the typhoon. Daily precipitation at that time was 393 mm and the water level rose to 3.3 m below the bottom of the girder. Pier No.10 was tilted 140mm towards the upstream direction (see in Figure 4c). Later, it was reinforced by sheet piles and riprap was placed around to protect the footing. The basic information about two bridges is shown in Table 2.

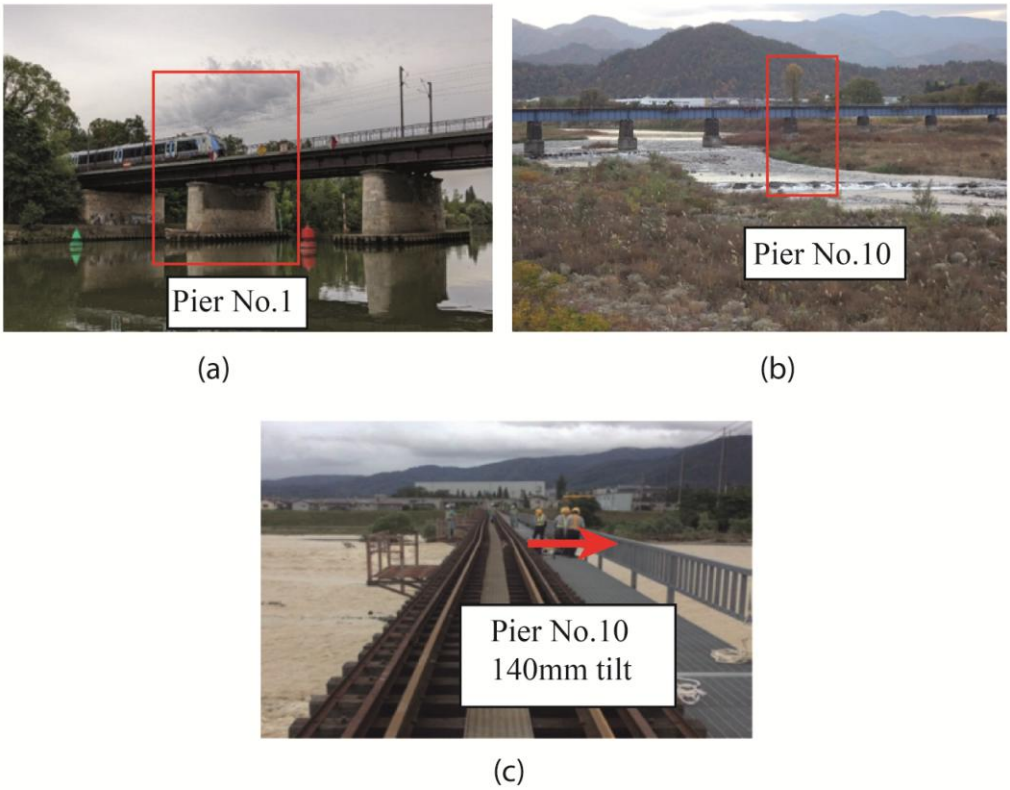


Figure 4 Photos of selected bridges for case studies: (a) Richebout bridge in France; (b) Ookawa bridge in Japan; (c) Tilting of pier No.10 (Ookawa bridge, Haiso et al., 2016)

Table 2 Characteristics of selected bridges for the case study

	Richebout bridge	**Ookawa bridge**
Circulation	Rail and road	Rail
Structural type	Masonry piers with steel deck	Masonry piers with steel deck
Construction year	1915	1925
Number of bridge piers	2	21
Total length	75m	439m
Foundation depth	5m	Min:3m; Max: 7m
Foundation type	Mass concrete protected by sheet piles	Caisson with unreinforced concrete

4. RESULTS

Before applying the two procedures, a methodological comparison is conducted at first to see their similarities and differences, and they are concluded and shown in Table 3. Section 4.1 presents the test results by using the two guidelines. Comparison results and future directions for improvements are discussed in Section 4.2.

Table 3 Summary of methodological similarities and differences between the Japanese and French methods

Similarities
• Same objective: assess scour risk of bridge element in a practical way. • Risk classes as an outcome, and in a binary form. • Both procedures neglect the social-economic consequences. • Don't calculate local scour depth, general scour depth with design flood level to conclude risk level.
Differences
• Foundation depth plays an important role in Japanese approach, but it is not included in the French method due to the difficulty for accessing data. However, variables in ML model such as the bathymetry evolution, and types of damages, in some ways reflects this information. • Parameters for describing hydrology and hydromorphology are not included in Japanese method, because information is considered already covered in topographical landform, riverbed materials, and hydraulic conditions. • The influence of riverbed particle to scour is different. Japanese model doesn't include cohesive soil (e.g., silt, clay), which is commonly seen materials in the French river. Cohesionless soil (e.g., sand) is considered as the material most likely to increase scour risk in French method. • The French ML model comprises the history of the structure (e.g., scour history, flood history) while the Japanese procedure doesn't. • In Japanese procedure, the hydraulic structure in the vicinity is an important factor and the bridge can directly be considered at high risk while French method doesn't take into account of this feature. • The protection condition is scored differently in Japanese guideline based on the scour countermeasure types. The French ML model considers the different scour countermeasures having the same influence.

4.1 Application results

The two bridges are evaluated by Japanese guideline at first and the results are shown in Table 4. As a reminder, the threshold value for scoring table is 110. A detailed inspection and more complex studies shall then be needed when the score is less than 110. Regarding Ookawa bridge in Japan, the pier No.10 is evaluated at the moment when the flood event just passed by, and the regeneration work hasn't started yet.

Table 4 shows the results by applying the scoring table to two bridges. It is observed that the total score of Ookawa bridge is much smaller than the threshold value. However, for Richebout bridge in France, the score (115) is very near but still above the threshold value (110). In the end, it's evaluated as in safe status.

Table 4 Test results by applying the scoring table

		Richebout bridge	**Ookawa Bridge (before regeneration work starts)**
Environment	Topographical	10	0
	Constriction of river width	15	15
	Riverbed material	0	0
	Overall riverbed degradation	10	10
Structural condition of bridge pier	Bridge pier location to river bend	15	15
	Bridge pier location relative to floodplain	5	0
	Downstream drop structure	20	20
	Relative embedment depth	20	10
	Bedrock contact	0	0
Protection condition against scour	Protection (Sheet piling)	20	0
	Total score:	**115**	**70**

The French ML model is then applied to evaluate the two bridge piers. Table 5 presents the prediction probability and prediction class. The threshold for ML model to determine the class is 0.5. Like the Japanese method, Richebout bridge is considered at low scour risk and Ookawa bridge is at high scour risk.

Table 5 French ML model evaluation results

	Prediction probability		**Prediction class**
	Low scour risk	**High scour risk**	
Richebout bridge	0.896	0.104	Low scour risk
Ookawa bridge (before regeneration work starts)	0.158	0.842	High scour risk

4.2 Discussions

This paper demonstrates how to apply Japanese and French guidelines for railway bridges' scour risk assessment. Compatible results have been obtained by applying two procedures to two countries' bridges. The total score of Richebout bridge (in France) is very near the threshold value when evaluated by the Japanese guideline, even though no obvious damage is observed for this bridge. To understand why it happens, firstly, the nature of two methodologies is not the same: the French one is a data-driven approach, but the Japanese guideline is calibrated by engineers' experience. Nevertheless, the common objective of the two guidelines is to screen high scour risk in an effective way. Bridges evaluated at high risk will need a detailed inspection, reinforced surveillance, or completed geotechnical and hydrological studies.

It can be observed from Table 3 that the parameters required in each guideline are quite different, which is primarily caused by the ways of managing the railway infrastructure. In France, when the water level is high, an underwater foundation inspection through diving is conducted. However, the impact vibration test is often adopted in Japan to know the status of bridge piers by comparing the natural frequency (Nishimura & Tanamura, 1989). The second reason is the different hydrological conditions. From a general view, compared with Japan, watercourse in France is more stable in terms of velocity and river diversion. Therefore, it causes the differences for riverbed material, the impact of riverbed material to scour and the important role of hydraulic structures (e.g., weir, dam) near bridges.

Regardless of the different maintenance policies, both countries need to enhance the resilience of railway infrastructure under the climate change challenge, especially considering the great number of historical assets in the rail network. The practical guidelines need to incorporate the effects of climate change and project the bridge scour risk under different climate models. Besides, currently only hazard and vulnerability factors are included in the guidelines. The socio-economic impacts namely the direct and indirect costs of a bridge closure or failure may be included. It will certainly optimize decision-making and help transport agencies adopt actions timely. In the end, both procedures only provide two class classifications. It is still difficult to prioritize maintenance considering the number of rail assets that need to be managed. A multiclass model for risk segmentation linked with maintenance work could be very helpful in practice.

5. CONCLUSIONS

More extreme flood events have happened recently due to the accelerating climate change. Enhancing the resilience of railway infrastructure to natural hazards shall be important. This paper studies the Japanese and French scour risk assessment procedures. It compares their similarities and differences, analyzes the reasons for differences existing in two approaches, and

most importantly, proposes insights for future improvements. Future work will consider adding other countries' procedures for comparison.

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