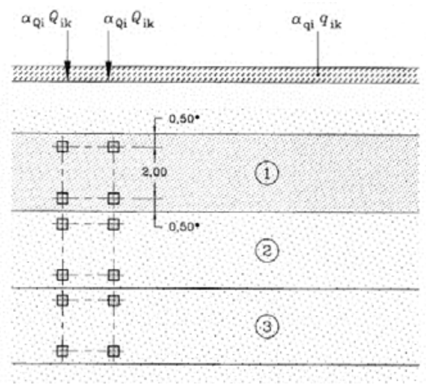
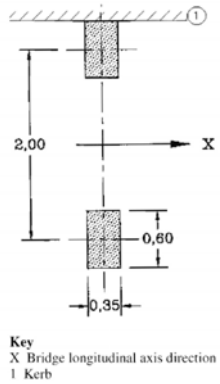
M_{LM2-AB}= -126.0 kNm/m respectively. Both moments are smaller than the maximum moment by LM1. Thus the maximum moment by LM1 is taken as the design moment in this example.



(a) Load Model1



(b) Load Model2

Fig. 4 Traffic Load in SDM (HK)

Table 8 Characteristic Values and Adjustment Factors for Load Model 1

Location	Tandem Sysdtem TS		UDL system	
	Q_{IK}	α_{Qi}	q_{ik}	α_{qi}
Lane1	300 kN	1.20 (1.44)*	9 kN/m^2	0.53 (0.64)
Lane2	200 kN	1.00 (1.20)	2.5 kN/m^2	1.91 (2.30)
Lane3	100 kN	1.00 (1.20)	2.5 kN/m^2	1.91 (2.30)

* The values shown in parentheses are used for the case where the loaded length is less than 60m and the total number of notional lanes on the bridge is greater than or equal to 6.

3.4 Varifications

The verification of the allowable stress design applies adjustment factors to the calculation value of internal forces. SDM(Japan) takes into account the influence of the length of slab span and the combination actions. On the other hand, the verification for SDM(HK) which is designed by the Ultimate Limit State is also carried out by using the partial and combinations factors.

3.4.1 SHB(Japan)

There are 2 type of adjustment factors. One is given depending on slab span length. The slab span is wider as the number of vehicles and heavy vehicles increases. We have to consider this influence in the design bending moment for the main bar. Table 9 shows the adjustment factor r_{j1}. Another adjustment factor is combination of actions. On Cantilever part (*Span AB, CD*), the action load includes permanent load, live load, collision load. In this case, the adjustment factor r_{j2} of concrete slab is 1.5. The design moment can be obtained by dividing the original design moment by r_{j2}. Generally, the design of bridge is considered unfavorable situation. However, such an unfavorable situation will not occur frequently. Hence, we can reduce the design internal force which considers several situations. Those results of calculations are shown in Table 10.

Table 9 Adjustment factor r_{j1} of bending moment of main bar direction in SHB(Japan)

Slab Span	L ≤ 2.5m	2.5 < L ≤ 4.0
Adjustment factor r_{j1}	1.0	1.0 + (L-2.5) /12

3.4.2 SDM(HK)

Basically, the verification of Ultimate design should be carried out by using Eq. (3) which is given by BS EN 1990.Values of those factors are specially defined for Hong Kong condition. Here, we use Design Values of action (STR/GEO) in SDM.

$$\sum_{j\geq 1}\gamma_{G,j} G_{k,j} + \gamma_p P + \gamma_{Q,1} Q_{k,1} + \sum_{i>1}\gamma_{Q,i}\psi_{0,i} Q_{k,i} \tag{3}$$

where G is permanent loads, P is prestressing, Q_k is characteristic value of variable action, γ is partial factor of each load and actions, ψ_0 is combination factor. Table 11 shows each design value of bending moment with the relevant partial factors.

Table 10 Values of calculation and design bending moment in SHB (Japan)

SHB (Japan)	Moment by Dead load (kNm/m)			Moment by Live load (kNm/m)			Design Moment
Location	Pavement	Concrete	Fence	T-Load	Collusion	Adjustment factor	Total (kNm/m)
Mid-span (BC) /Main bar	4.5	14.7	---	55.0	---	1.125	84.48
Mid-span /Distribution bar	Neglect	Neglect	---	44.0	---	---	44.0
At Support(B, C) /Main bar	-0.91	-10.36	-1.15	-59.36	-30	1/1.5	-67.856
At Support /Distribution bar	Neglect	Neglect	---	22.75	---	---	22.75

Table 11 Values of calculation and design bending moment in SDM (HK)

SDM (HK)	Moment by Dead load (kNm/m)			Moment by Live load (kNm/m)					Design Moment
Location	Pavement	Concrete	Fence	LM1 TS	LM1 UDL	Collusion	LM2	Partial factor (Unfavorable)	Total (kNm/m)
Mid-span (BC) /Main bar	4.4	15.0	---	275.6	9.54	---	273.8 < LM1	Road surfacing 1.20 Concrete/other material 1.35 Road traffic action 1.35	408.909
Mid-span /Distribution bar	---	---	---	---	---	---		---	---
At Support(B, C) /Main bar	-1.10	-11.95	-1.25	-144.0	-2.39	-30	-126.0 < LM1	Road surfacing 1.20 Concrete/other material 1.35 Road traffic action 1.35	-257.26
At Support /Distribution bar	---	---	---	---	---	---		---	---

4. RC-SLAB DESIGN REINFORCEMENT ARRANGEMENT

Both codes have their own structural design. Here, we will design the RC-slab following each structural design for those design moment. As design strength of concrete for slab, the characteristic cylinder strength f_{ck} is used and its value is more than 24 N/mm^2 in SHB(Japan). In the case of composite bridge which considers composite action with concrete slab and steel girder, f_{ck} shall be more than 27 N/mm^2. In the case of the slab has a prestressing, the value of f_{ck} shall be 30N/ mm^2. On the other hand, SDM(HK) uses the characteristic cube strength $f_{ck,cube}$ and it shall be of 40 N/mm^2 or stronger. SDM(HK) also assumes $f_{ck,cube}$ = 40 N/mm^2 equal to f_{ck} = 32 N/mm^2. In this sample calculation, we will use f_{ck} = 32 N/mm^2 as the design strength of concrete.

4.1 Structure Design of SHB(Japan)

The requirements for design of reinforcement arrangement have been revised by major earthquakes. After the 2011 Tohoku earthquake, the yield strength of reinforcement with which is used in concrete slab is required to be more than 345N/mm^2. The tensile allowable stress σ_{sa} is given 140N/mm^2. The concrete compressive allowable stress is defined to be one third of the design strength. It means the allowable stress of concrete σ_{ca} is 10.6 N/mm^2 (=32N/mm^2/3) .The concrete design strength should be larger than 30N/mm^2.

The amount of required reinforcement is determined by the design bending moment. At first, we need to estimate the amount and verify whether the stress within the allowable stress. In addition, the estimation should consider the following requirements for reinforce arrangement. Here are the main requirements.

1) Reinforcement shall be a deformed reinforcing bar, and the diameter should be 13, 16, 19mm. (22mm can be allowed only in specific cases.)
2) Concrete cover (which is the distance from surface of concrete to center of reinforcing bar) shall be more than 30mm.
3) The distance from the center of each reinforcing bar is more than 100mm and less than 300mm. In addition, the spacing of tensile side reinforcement will not be larger than the slab thickness.
4) The amount of reinforcement of compression side should arrange at least more than half amount of the tensile side.

Generally, the ratio of Young's modulus for the calculation of the stress of concrete is n=15. However in the case of composite bridge which considers composite action, n can be 7 for the calculation of the elastic deformation and internal stress of main girder. Here, we calculate the stress of the concrete slab. Thus, we use n=15. The compressive stress of concrete and the tensile stress of reinforcement can be represents Eq.(4) and Eq.(5).

$$\sigma_c = \frac{Mc}{Wc} < \sigma_{ca} = 10\,N/mm^2 \tag{4}$$

$$\sigma_s = \frac{Mt}{Ws} < \sigma_{sa} = 140\,N/mm^2 \quad (5)$$

where,Mc is the design moment of compression side; Mt is the design moment of tension side,Wc is section modulus of compression side concrete, Ws is section modulus of tension side reinforcement. Following the above structure details and requirements, the amount and the arrangement of the required reinforcement can be obtained.(Table 12)

4.2 Structure Design of SDM(HK)

The specification of reinforcing steel which is used in bridge complies with other civil engineer works. Reinforcement should use grade 500B and grade 500C. Both specified characteristics strength f_y are 500 N/mm^2. As the calculation of reinforcing bar arrangement, the K value is calculated by Eq.(6).

$$K = \frac{M}{b d^2 f_{cu}} \quad (6)$$

where M is the design ultimate moment at the center of the span or, for a cantilever, at the support, b is the width of the slab cross-section, d is effective length, and f_{cu} is the characteristic cube strength of concrete. If the K value is less than 0.156 it can be designed as a singly reinforced section. If the K value is over than 0.156, compression reinforcement is required. In this example calculation, both K by $M_{LM1\text{-}BC}$ and $M_{LM1\text{-}AB,CD}$ are less than 0.156. Thus, we design it as a singly reinforced section. The lever arm z (the distance between compression force in concrete and tensile force in steel reinforcement) can be calculated by Eq.(7).

$$z = d\left[0.5 + \sqrt{0.25 - K/0.9}\right] \quad (7)$$

Then, the required area of steel reinforcement can be calculated by Eq.(8).

$$As = \frac{M}{0.87 f_y z} \quad (8)$$

4.3 Comparison of Reinforce Arrangement

The required area of steel reinforcement and arrangement by both codes are shown in Table 12. To compare the areas of reinforcement, total areas are counted by the minimum requirement. At the middle span of the main bar, the amount of reinforcement of tension side in *SDM* is 1.7 times larger than *SHB*. Although *SDM* doesn't need any reinforcement in compression side and the strength of reinforcement bar in *SDM* is larger (f_y = 500N/mm2) , the total required amount is more than *SHB*. On the other hand, the reinforcement of distribution bar at the middle-span, the amount of SDM is significantly small and very thin reinforcement bar is used. In *SHB,* it allows using diameter of reinforcement bar of 13mm, 16mm, 19mm, 22mm (in specific cases) because bold steel bar has a possibility to cause large cracks, and thin steel bar is easy to bend during construction.

In addition, for further discussion, we try to design by using design moment of SDM and structure detail of SHB. Table 13 shows the result. Here we use f_y = 345 N/mm^2 as the strength of the steel bar and the range of diameter is used from 16 to 22mm. From the calculation result, we can see it needs huge amount of reinforcement even though only the tension side was considered. Thus, it cannot meet the minimum distance (100mm) for each reinforcement bar of SDM's structural details. Through a series of these calculations, although SHB uses smaller strength of reinforcement bar, it has a well-balanced arrangement. SHB also considers the influence of distribution bar and it seems to have effects of ductility and toughness. Ductility has important effect in reducing damages by the seismic actions of earthquakes. SDM has less consideration not only for the effect of distribution bar, but also the balance of arrangement.

Table 12 Reinforce Arrangement of Concrete Slab

		Tension side			Compression side		Total
Location	CODE	As_min (mm^2) "Requirement"	As (mm^2) "Design"	Arrangement of reinforced bar (Diameter @ Distance)	As' (mm^2) "Design"	Arrangement of reinforced bar (Diameter @ Distance)	As_min + As'
Mid-span /Main bar	SHB (Japan)	2650	2865	D19@100mm	1432.5 (= As/2)	D19@200mm	4082.5
	SDM (HK)	4586	4908	D25@100mm	---	*K=0.151<0.156 It is not required	4586
Mid-span /Distribution bar	SHB	1715	1986	D16@100mm	993 (= As/2)	D16@200mm	2708
	SDM	338	392	D10@200mm	---	---	338
At Support /Main bar	SHB	2140	1910	D19@150mm	955 (= As/2)	D19@300mm	3095
	SDM	2583	3140	D20@200mm	---	*K=0.095<0.156 It is not required	2583
At Support /Distribution bar	SHB	682	844.7	D13@150mm	422 (= As/2)	D13@300mm	1104
	SDM	338	392	D10@200mm	---	---	338

As_min: Area of the minimum requirement of reinforcement; As: Area of design reinforcement by arrangement of tension side; As': Area of design reinforcement by arrangement of compression side, The specified characteristics strength of SHB $f_{y\text{-}SHB}$ is 345 N/mm^2,The SDM $f_{y\text{-}SDM}$ is 500 N/mm^2.

Table 13 Conversion to SHB from SDM

f_y = 345 N/mm^2		Tension side			Compression side	
Location	CODE	As_min (mm^2) "Requirement"	As (mm^2) "Design"	Arrangement of reinforced bar (Diameter @ Distance)	As' (mm^2) "Design"	Arrangement of reinforced bar (Diameter @ Distance)
Mid-span /Main bar	SDM (HK)	6646	6966	D22@<u>55mm</u>	3483 (= As/2)	D22@110mm
At Support /Main bar	SDM (HK)	3743	3768	D20@<u>80mm</u>	1884 (= As/2)	D20@160mm

As_min: Area of the minimum requirement of reinforcement; As: Area of design reinforcement by arrangement of tension side; As': Area of design reinforcement by arrangement of compression side

5. CONCLUSIONS

The example of calculation has presented the difference of the concepts of both codes. Although SDM (Japan) uses smaller strength of reinforced bar, it is arranged better and considers ductility. On the other hand, SDM(HK) uses the reinforcement of high strength and the main bar requires more amount of reinforcement. From translation to SDM's structure design, it is observed that the arrangement of reinforcement is concentrated in tension side and main bar direction. Further the challenge of this study, we will perform further experiments by using the model of these examples and comparing both failure modes.

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