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Comparative Analysis on Main Material index of China and International Composite Girder Bridge with Corrugated Steel Web

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ABSTRACT Prestressed Concrete girder bridge with corrugated steel web is type o girder bridge that evolve rapidly in recent year, its excellent mechanical properties is getting more and more recognition by majority of the bridge engineers. This article investigate the case study of constructed girder bridge with corrugated steel webs in China, analyze and give comment based on their construction design, technology and etc. With the data of constructed girder bridge with corrugated steel webs in Japan comparative analysis of the main material index of China and Japan girder bridge with corrugated steel webs was compared, the material index function was developed to ease the estimation of related construction.

KEYWORDS
Corrugated Steel Web
Composite Girder Bridge
Material Index
Rapid Construction

1. Introduction

Girder bridge with corrugated steel web originate from French.It is relatively late beginning in China, the first girder bridge with corrugated steel web-Jiangsu Huai'an Long March Bridge (footbridge) was completed in year 2005，and this opened the prelude of the construction of girder bridge with corrugated steel web in China. This after, the first model girder bridge with corrugated steel web was completed in year 2006-Henan Guangshan Bohe Bridge， detail investigation was conducted on the model bridge since design stage to the construction works, load test was conducted after the completion of project, test results is normal. Several of short span girder bridge with corrugated steel web was constructed then. Until year 2011 when Shandong Juan City Yellow River Highway Bridge was constructed, it led to the construction of long span girder bridge with corrugated steel web in China. Till date the constructed long span reached 200 m. The overall scale of girder bridge with corrugated steel webs is more than Japan.

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This article highlights the constructed girder bridge with corrugated steel webs in China, review in terms of structure design, construction method, the choice of connection and other pattern. Statistical analysis was carried out for the amount of major material used on the superstructure of girder bridge with corrugated steel webs (includes concrete, steel, corrugated steel web, prestressed tendons), analyze together with the statistical analysis data of Japan. For the design and construction of the girder bridge with corrugated steel web, the production of corrugated steel webs was summarize and analyze, to provide information and reference for future design and construction.

2. Girder Bridge with Corrugated Steel Web in China

Although it is relatively late beginning on the research on the girder bridge with corrugated steel web in China, but many research institutes have been conducted the study, and with remarkable achievement, rapid development within the country in recent year. Currently, the girder bridge in China that was built, is constructing and in design stages, has total number of more than hundred. More than 20 provinces throughout the country, municipality, and the distribution were shown in Figure 1.

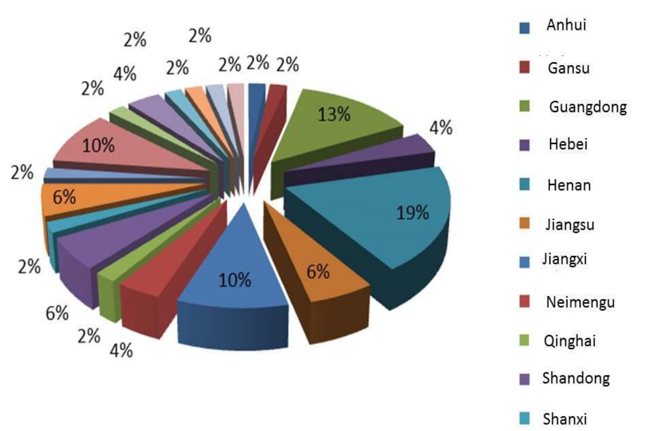


Figure 1 Distribution of Girder Bridge with corrugated steel web in China

The girder bridge with corrugated steel web in China is restricted to road and municipal bridge till now, from initially the short span small girder, rapidly evolve to long span girder bridge, the main function is the use of corrugated steel web is more economical for the large span bridges.

After all the hard work of bridge engineers, to explore new viewpoint, the construction of girder bridge with corrugated steel web in China continues to break records, increasing the scale of construction. Till date the girder bridge that was built, is constructing and in design stages, the total numbers of bridges that their main span that is more than 100 is more than 30. The bridge structure pattern is variety, such as simply supported beam bridge （Qinghai Sandao River Bridge）, continuous beam bridge （Shandong Juancheng Yellow River Highway Bridge）、continuous rigid frame bridge（Sichuan Xugu River Highway Bridge）、stayed bridge （ZhengDeng Expressway Choyanggou Bridge）、cable-stayed bridge（Nanchang Chaoyang Bridge）. The cross section of box beam in the form of single-box single-chamber, single-box two-compartment, single-box three compartment and etc.

2.1 Concrete and Prestressed

The concrete use for the superstructure of girder beam bridge with corrugated steel web in China is normally as C50, C55 or C60. Till date, there is no other concrete grade been used. The reinforcement bar for the box girder is same as the general concrete. The prestressing system, usually use top and bottom, inside and outside combining stress prestressing system. For the long span cross section girder, other than tension prestressing, vertical prestressing should be set at the no 0 sid. This is same as the basic of concrete girder bridge. It is noted that the girder bridge with corrugated steel webs is more efficient than the ordinary concrete prestresed girder bridge, due to that the roof to floor is still the concrete, the loss of prestressing strength due to shrinkage and creep need required further investigation.

2.2 Corrugated Steel Web

As the corrugated steel web is the major structure, the research tends to more focus on the corrugated steel web, the papers of experts in China and related standards has provides the theory and implementation basis on the structure of girder bridge with corrugated steel web. As there is an outgrow of the professional manufacturers of corrugated steel web, the uses of continuous multi-wave molding process, the quality and availability of corrugated steel web is guaranteed.

Material and shape of corrugated steel web

The corrugated steel web in China mainly uses high strength low alloy structural steel. Q345C or Q345D was used in the southern region, Q345D or Q345E was used in the northern region, some use steel. In recent year, weathering proof steel bridge was gradually use in the girder bridge with corrugated steel web, there is some case with painting free, this can be set as the reference for the related construction of girder bridge in future. T is usual to use the high strength steel for the long span steel bridge in China, there is yet any case of usage for the girder bridge with corrugated steel webs.

The shape of corrugated steel web, normally use type 1200 roll steel for the short span bridge use type 1600 roll steel for the long span, currently the type 1600 roll steel was the major type. The thickness of the corrugated steel web is ranging from 10mm to 32m respectively, the corrugated steel webs with thicker size was located at location with higher shear strength, usually at the support where the concrete web lining was used, this can reduce the thickness of steel plate, in accordance with the calculation. Connection of corrugated steel plate

The usual connection pattern of corrugated steel plate and substructure of concrete are: stud connection, embedded connection, double opening panel connectors, single opening panel connector, single opening+stud connection, angle conncetion and etc., these few types of the free combination pattern, except than the embedded connection, required the flange. The connection of corrugated steel web and the top plate is stronger than the connection of corrugated steel web and the bottom plate. There is also other connection method, which discussed in related publication and design drawing, but not widely in use.

The connection of corrugated steel web and diaphragm, normally will be the stud connection in China, there is also use the single opening+stud connection. The connection of steel web and concrete lining, normally will be the welded stud connection. Stud may be arranged in a straight or diagonal band. The connection between the steel web and the beam is the embedded connection, that is plate opening hole, inserted thoroughly the reinforcement bar, filled with concrete.

Corrugated steel web often produced as the end product from the manufacturer factory, which the top flange is connected well through welded, required only the sectional connected through welding at field. Although there is a few of the proposal for the connection of the steel web, but the majority practice is the use of temporary fixing bolts, later double welded.

Coating of steel web

The coating of corrugated steel web, the method that currently in uses, normally is the long-lasting anti-corrosion system in accordance with the standard such as "Anti-Corrosion Technology of Highway Steel Bridge" （JT/T 722）, assure the quality and film thickness. Considering the environment of both the inner and outer of girder web is different, the coating of outer side is stronger, with the anti-water measure. Meanwhile weld grinding zone at the field and the damage of coating at local area during the process, both required on site coating, to ensure the serviceability of the structural element.

Construction method of girder bridge with corrugated steel web

Although the application of girder bridge with corrugated steel web is late started, but the construction method is comparatively flexible. The uses of construction method to date are: in-situ bracket method（Zhengzhou Longhu Loop Bridge）, cantilever construction method （ Shandong Juancheng Yellow River Highway Bridge）, prefabricated method（Henan Guangshan Po River Bridge）, thrusting method（Zhenzhou Changzhuang Main Canal Bridge）. Due to the limitation of environmental factor (across the river, reservoir, railroad and etc.), bridge engineers are talented, improving the construction technology of girder bridge with corrugated steel web from time to time, achieve the top in China, and the top of the world. After several years of construction, the construction work of girder bridge with corrugated steel web continuously getting improved and enhanced, more efficient construction methods and usage will be further studied.

It is important to mentioned that the Yuwotou Bridge at Guanngzhou，the structural pattern of the bridge is girder bridge with corrugated steel web, the whole bridge is 120m lon, span setting is 35m+50m+35m. It is the first curved girder bridge with corrugated steel web, the radius of the curve is the smallest in the world R=110m, which also the first using the continuous wave molding to form the girder of the beam bridge. The bridge mainly use the corrugated steel web as the temporary load bearing member (as in Figure 2), completed at the factory as corrugated steel web, according to the design requirement, fixed the corrugated steel web at certain length on the ground, transfer the corrugated steel web on the road during low traffic volume (before the dawn) to the pier, use the corrugated steel web as stiffening supporting framework, on site construction of concrete substructure and superstructure, constructing, the downside of the bridge required no supporting system, to minimis the influence on the traffic flow. The construction method is a good reference to the construction works of municipal bridge and cross border bridge.

In addition to the excellent performance of girder bridge with corrugated steel web, the SCC (self-supporting cantilever casting) which based on the RW construction method at international standing, is significantly increase the performance of construction works, which was promoted rapidly now. The details of the method were discussed in the related article.

For the production and work requirement, the section of steel web could be designed more flexibly, the root of the web section should be controlled at below 3.2m, the length for the web at lower height section could be within 4.8m to 6.4m, if could be extended if conditional allowed, this is to ensure the accessibility of transport, storing and fixing. This should be considered during the design stage of girder bridge with corrugated steel web.


Figure 2 The construction work of GuangZhou Yuwoutou Bridge

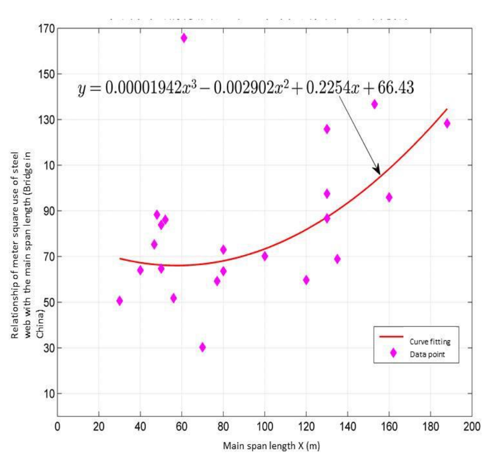
3. Material Index and Analysis of Girder Bridge with Corrugated Steel Web in China and International

This article gathers the information of the material index and usage of 22 local and 27 international (mainly Japan) girder bridge. The data is summaries in Table 1 and 2. The data shown in both table did not considered the difference on the bridge model, only summarize the usage of the material in constructing the superstructure.

By utilizing the data shown in Table 1 and 2; taking the span of the bridge as the manipulator variable, the usage of the material as the responsive variable, numerical analysis was run through the MATLAB programming software, to conduct the data simulation and analysis, developing the function between span of the bridge and the usage of the material. The curve fitting results was shown in Figure 3 , 4 and 5, meter square indicate the area of the bridge in unit.

Figure 1 Summary of material use for the girder bridge with corrugated steel web in China

Bridge Name	Main Span (m)	Concrete (m^3/m^2)	Reinforcement Bar (kg/m^2)	Prestressed tendon (kg/m^2)	Steel Web (kg/m^2)
Zhenzhou Xinmi Qin waterway Main Bridge	70	0.807707692	131.0803385	39.29775385	30.3
Zhenzhou Longhu Central Road Bridge	56	0.779968479	201.4369582	40.52115051	51.75388495
Shandong Juancheng Yellow River Bridge	120	0.800540335	127.3094876	51.14510401	59.71182141
Neimenggu Jingjiawan Bridge	80	0.849878049	147.6077747	40.87603491	63.57766614
Jiangshu Jinma Highway Bridge	40	0.720608333	127.8604167	32.0745	63.99208333
Henan Taohuagu Yellow River Bridge	135	0.941443953	191.7328524	57.37541673	68.9108597
Ganshu Xiaoshagou Bridge	100	0.971104851	232.0900294	54.10019598	70.10938266
Neimenggu Changchonggou Bridge	80	0.896521008	169.5318067	41.85346639	72.95172269
Zhenzhou Changzhuang Main Cananl section	50	0.685690446	157.5101752	30.33699207	83.86628285
Henan Daguang Highway Bridge	52	0.670826389	154.9327263	44.69330515	86.11438559
Shenzheng Pintie Bridge	130	1.084929757	151.7762452	55.79412516	86.7210728
Nanchang Zhaoyang Bridge	48	0.715170898	153.5721436	44.79351237	88.33541667
Zhuhai Qianshanhe Bridge	160	1.103436041	199.0244538	71.62948646	95.91792717
Shenzhen Nanshan Bridge	130	0.972647096	181.0376516	57.6413529	97.48564135
Sichuan Xugu Highway Bridge	130	1.102341849	206.1193735	65.11131387	125.8071776
Zhenzhou Chaoyanggou Bridge	188	1.111755448	244.0859564	44.95157385	128.311138
Hefei Nanfeihe Bridge	153	1.179883382	174.3298105	73.2578	136.7306
Jingganshan district Jingji Railway Bridge	61	0.720859729	87.90565611	51.098	165.768
Xian Xixian Highway Bridge	30	0.467272727	77.1	19.5419	50.597
Guangzhou Yuwotou Bridge	50	0.592380952	123.0769841	24.5391	64.6724
Zhenzhou Zhihuan Road Bridge	77	0.762714356	101.6199902	28.805	59.2581
Zhenzhou Jingguang Road Bridge	46.7	0.705446623	80.34213508	25.6331	75.2863



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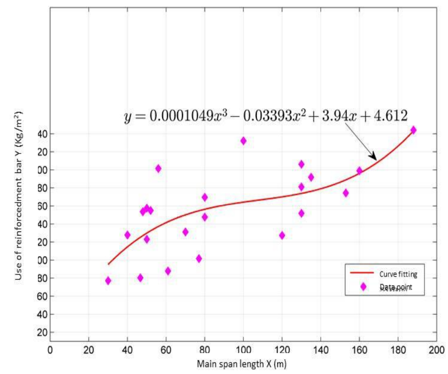

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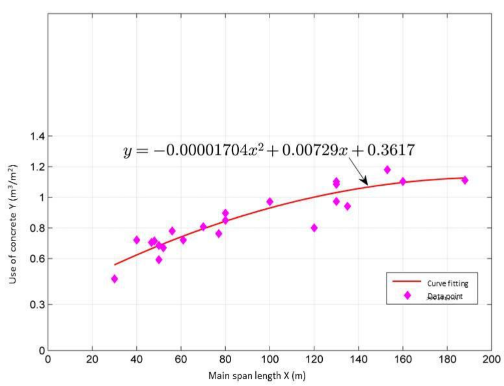

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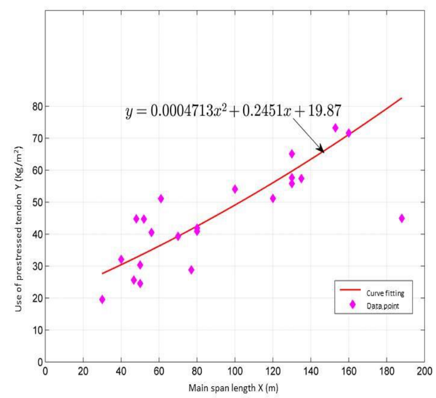

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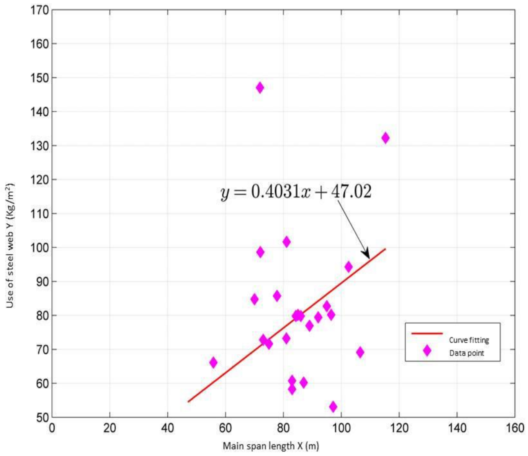
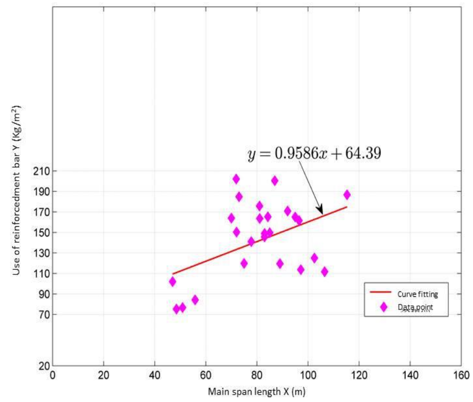
Figure 3 Result of data fitting for material index of girder bridge with corrugated steel web in China. A) Relationship of meter square use of steel web with the main span length; B) Relationship of meter square use of reinforcedment bar with the main span length; C) Relationship of meter square use of concrete with the main span length; D) Relationship of meter square use of prestressed tendon with the main span length

From Figure 3 can be seen that, the relationship of meter square use of steel web in China (y) with the main span length (x) is: $y = 0.00001942x^3 - 0.002902x^2 + 0.2254x + 66.43$; the relationship of meter square use of reinforcement bar in China (y) with the main span length (x) is: $y = 0.0001049x^3 - 0.03393x^2 + 3.94x + 4.612$; the relationship of meter square use of concrete in China (y) with the main span length (x) is: $y = -0.00001704x^2 + 0.00729x + 0.3617$; the relationship of meter square use of prestressed tendon in China (y) with the main span length (x) is： $y = 0.0004713x^2 + 0.2451x + 19.87$。Although the bridge shown in Table 1is individually design by different local institutes, the material usage index is more consistent, this illustrates that the consistency of design standards, the span of the design is also increasing gradually.

Table 2 Summary of material use for the oversea girder bridge with corrugated steel web

Bridge Name	Main Span (m)	Concrete (m^3/m^2)	Reinforcement Bar (kg/m^2)	Prestressed tendon (kg/m^2)	Steel Web (kg/m^2)
Neuko Bridge	48.5	0.59037871	75.33265097	33.32650972	29.47799386
Tanigawa Bridge	50.9	0.598465473	76.72634271	38.75532822	40.92071611
Tsurumaki bridge	47	0.586734694	102.0408163	24.85012755	42.5170068
Valley Bridge	97.2	0.743601313	113.6856261	35.83574418	53.0827826
Nakano (3) West Bridge	83	0.698902027	145.6925676	33.28040541	58.27702703
Tanigawa Bridge (on)	87	0.933686534	200.4415011	45.19258278	60.22075055
Nakano (2) East Bridge	83	0.711532249	149.0255195	34.22246151	60.73005276
Anjia 4 Bridge	55.8	0.659835281	84.2750431	35.14652365	66.07929515
Zhishan Bridge	106.5	0.611193139	111.7244882	53.23737692	69.12247374
Tsukumi River Bridge	75	0.627549218	119.7931721	29.47072615	71.61897421
Second Shanping Bridge	73	0.908528637	184.8105446	41.34150278	72.81535455
Xiaoquanyanchuan Bridge	81	0.846296752	175.7056203	41.4168364	73.19202274
XinYue (7) Bridge	89	0.691383671	119.5207129	36.82321773	76.92076108
Hasegawa Bridge	92	0.88678526	170.9021601	46.37573062	79.41550191
Shiraiwa bridge	86	0.95140835	16.03096946	41.9655156	79.79860352
Jeongok Bridge	84.3	0.814411518	165.2593213	43.16041473	79.79987775
Guang Nei Second Bridge	85	0.814488497	149.7044316	31.99909635	80.12349863
ShengShouChuan Bridge	96.5	0.819180897	161.501222	37.70956243	80.16687162
Tanigawa Bridge	95	0.853624208	165.0246305	34.2364532	82.68824771
Kurobe River Bridge	70	0.795070563	163.9833035	38.63546015	84.72470682
XiaoHenei Bridge	77.8	0.848264778	141.0798262	46.622418	85.71938806
Recreation River bridge	102.5	0.854082224	125.087227	44.02662094	94.27939364
Nagai 11 Bridge	72	0.745918925	150.3553855	26.54065453	98.60970085
Nakatsu bridge	81.1	0.941224466	163.5486785	43.21801148	101.6260163
Chiyo River Bridge	115.3	1.145090539	186.6905054	58.92975198	132.2217833
Kinugawa Bridge	71.9	1.057702143	202.0737434	63.46436044	147.0218998
IranTehran Highwway BR-06 Bridge	153	0.636531145	111.9911939	81.6244	34.4429





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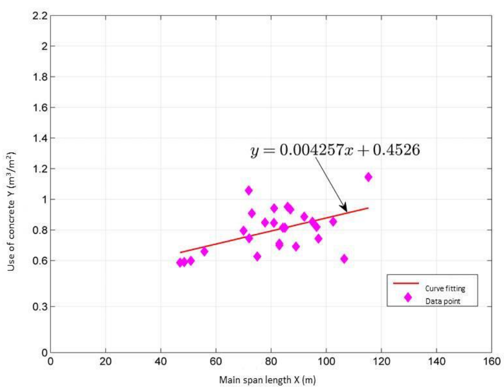

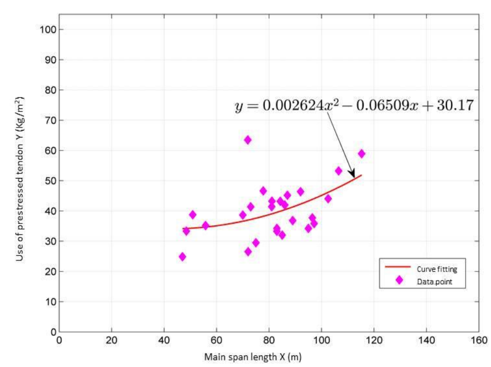

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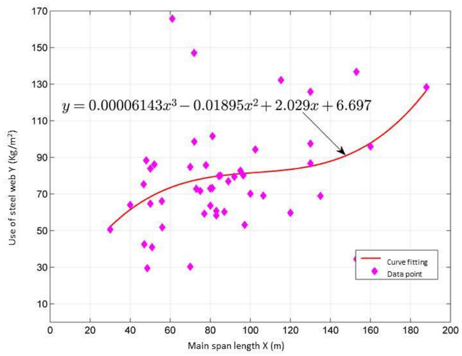
Figure 4 Result of data fitting for material index of oversea girder bridge with corrugated steel web. A) Relationship of meter square use of steel web with the main span length; B) Relationship of meter square use of reinforcedment bar with the main span length; C) Relationship of meter square use of concrete with the main span length; D) Relationship of meter square use of prestressed tendon with the main span length

From Figure 4 can be seen that, the relationship of meter square use of steel web at oversea (y) with the main span length (x) is: $y = 0.4031x + 47.02$; the relationship of meter square use of reinforcement bar at oversea (y) with the main span length (x) is: $y = 0.9586x + 64.39$; the relationship of meter square use of concrete at oversea (y) with the main span length (x) is: $y = 0.004257x + 0.4526$; the relationship of meter square use of prestressed tendon at oversea (y) with the main span length (x) is： $y = 0.002624x^2 - 0.06509x + 30.17$. Due to the limitation of data collection, the simulation result shows linear relationship, the results is not ideal. The range for the length of bridge span for local and international is different, contribute to the variation for the curve fitting line, but it can be noticed that the material usage index is approximate for both local and international.

The data of both local and international was integrated together for the simulation analysis, the result was shown in Figure 5



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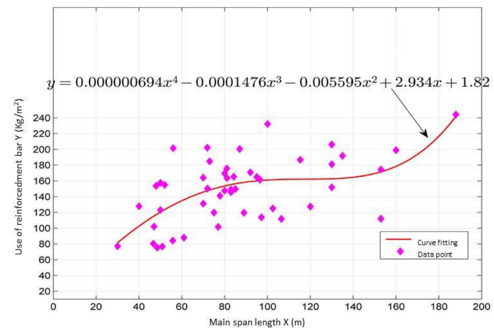

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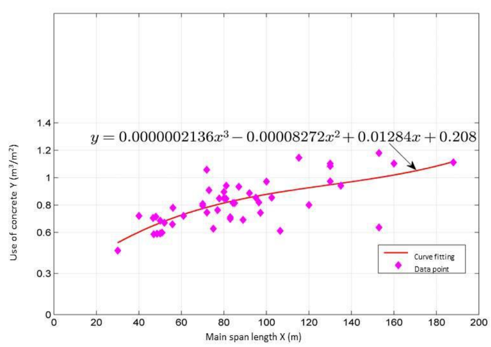

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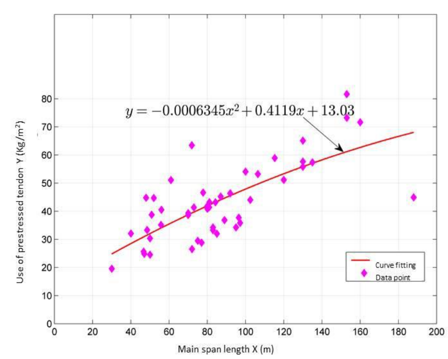

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Figure 5 Result of data fitting for material index of girder bridge with corrugated steel web in China and oversea A) Relationship of meter square use of steel web with the main span length; B) Relationship of meter square use of reinforcedment bar with the main span length; C) Relationship of meter square use of concrete with the main span length; D) Relationship of meter square use of prestressed tendon with the main span length

4 $y = 0.4031x + 47.02$； $y = 0.9586x + 64.39$； $y = 0.004257x + 0.4526$； $y = 0.002624x^2 - 0.06509x + 30.17$

From Figure 5 can be seen that, the relationship of meter square use of steel web for China and international (y) with the main span length (x) is: $y = 0.00006143x^3 - 0.01895x^2 + 2.029x + 6.697$ ；the relationship of meter square use of reinforcement bar for China and international (y) with the main span length (x) is: $y = 0.000000694x^4 - 0.0001476x^3 - 0.005595x^2 + 2.934x + 1.82$ ；the relationship of meter square use of concrete for China and international (y) with the main span length (x) is: $y = 0.0000002136x^3 - 0.00008272x^2 + 0.01284x + 0.208$ ；the relationship of meter square use of prestressed tendon for China and international (y) with the main span length (x) is： $y = -0.0006345x^2 + 0.4119x + 13.03$ 。Through the calculated results can shows that the relationship for the dataset that includes both local and international is more approximate to the exact values.

The developed function resulted in Figure 5can be used as the calculated equation in estimating the material usage for the girder bridge with corrugated steel webs for both China and international. Definitely, this article can also use other parameters, or use more than one parameter to develop the multivariable equation. Given the use of the bridge span is easy to be distinguish between different bridges, simple basis, easy controllability, this article only utilize the span length as the manipulator variables, ti simulate the relationship with the respective responsive variables. The data shows, the implementation of the girder bridge with corrugated steel web is relatively late in China, but with the rapid development, the design quality is relatively higher.

4. Conclusion

This article introduced the construction feature, structure detail and construction method of girder bridge with corrugated steel web in China, give the estimation function of material usage of girder bridge with corrugated steel web. The use of girder bridge with corrugated steel web on highway bridge has the own product code and local reference for the reference, the national standard was also in preparation stage. The prefrabicated of medium to small size span girder bridge with corrugated steel web need to be further research and promoted, the standard procedure for the technology and management of rapid construction of large span girder bridge with corrugated steel web required in depth study. Girder bridge with corrugated steel web as one of the excellent steel concrete composite structure, with the excel in mechanical properties and feasibility, is undergoes with rapid development.

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