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New Product and Utilization Technology of SMart BEAM™

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Abstract

SMart BEAM™ is a welded light gauge H section steel manufactured by Nippon Steel & Sumitomo Metal Corporation, which primarily has been used as a beam material of steel prefabricated house, whose market share in Japan has been over 80%. Recently, the manufacturing technology of welded light gauge H section steel, which has been established in the former Sumitomo Metal Industries, Ltd., is combined with the manufacturing technology of highly corrosion-resistant steel sheet, which has been brought up in the former Nippon Steel Corporation as "SuperDyma™", succeeding in developing and commercializing high corrosion resistance welded light gauge H section steel "SD-SMartBEAM™". In addition, the utilizing method of SMart BEAM, which can ease the vertical vibration problems, has been developed and proposed to the market as the substitute for wooden beams of the wooden houses, especially for the large span part. In this paper, a brief outline, as for the SD-SMartBEAM and the substitution technology for large span wooden beam, is introduced.

1. Introduction

SMart BEAM™ is a welded light gauge H section steel manufactured by Nippon Steel & Sumitomo Metal Corporation (hereinafter referred to as light gauge H section steel). SMart BEAM is the H section steel manufactured by using hot strip steel sheets and built up by welding. As the manufacturing method in **Fig. 1** shows, an H section is manufactured by using two hot-rolled steel sheet coils, one of the sheet coil is guided to the upper and lower flange position after slitted half, another is guided to the web position after twisted. So, by flowing a high frequency current between the flange and the web, and they are melted by the generated arc. Then, by applying pressure, the flange and the web are continuously welded.

Owing to the difference in the manufacturing process, when compared with the hot-rolled H section steel (hereinafter referred to as rolled H section steel), SMart BEAM is characterized by its abilities of "producing H section steel with thinner thickness," "providing high dimensional accuracies," and "providing high affinity with electrodeposition coating and powder coating as hot-rolled strip sheets with flat and smooth surface are used as the mother material."

As for the product standard, the light gauge H section steel of 400 N/mm^2 class is provided as SWH400 in JIS G 3353 (Welded light gauge steel H sections for general structure), and it is possible to apply them to the major structures of buildings as the architectural material designated by Article 37, Section 1 of the Building Standards Act. Furthermore, in Nippon Steel & Sumitomo Metal, light gauge H section steel of 490 N/m^2 class is manufactured, which is standardized as NSSWH490 in Nippon Steel & Sumitomo Metal Merchandize Standards. Moreover, as to NSSWH490, the ministerial authorization provided in Article 37, Section 2 of the Building Standards Act was obtained and NSSWH 490 is authorized to be used for major structures of buildings.

Nippon Steel & Sumitomo Metal started the commercial production in October 1973, and the accumulated amount of the production reached 5 million tons in July 2014. At the early stage, light gauge H section steel was used mainly for the main frame of low-rise buildings like manufacturing plants from the view point of saving steel material weight. However, as such manufacturing plants grew larger in size along with the elapse of time and the rolled H section steel has come to be used for main frame of such buildings as materials in main stream. On the other hand, since around the end of 1970s, in the steel-framed prefabricated houses, light gauge H section steel has come to be used from the viewpoint of sectional performance efficiency, substituting the beam material that was built up of two light gauge channel sections jointed together back to back.

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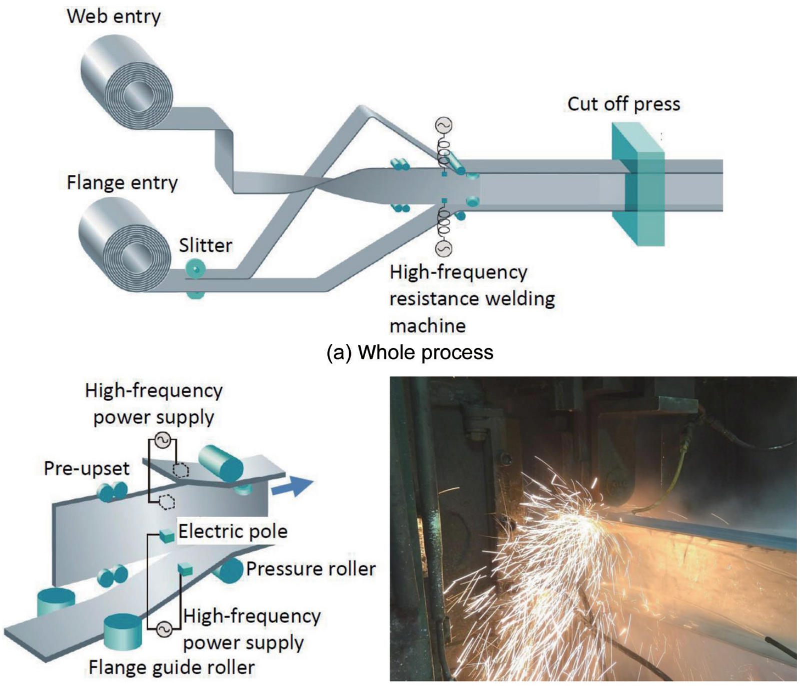


(b) High frequency resistance welding

Fig. 1 Manufacturing process of a SMart BEAM

As factors lying in the background, following features of light gauge H section steel are listed: the production of light H with relatively thin thickness is possible, the dimensional accuracy is very high, and the surface is flat and smooth. Such features mean that light gauge H section steel is well suited to automatic processing lines such as of hole opening by a punching machine, of cutting a member material by shearing, and of electrodeposition coating. Since after, as the steel-framed prefabricated houses have evolved to high quality industrialized houses and spread as the result of defection from the extension of temporary houses in the early period, light gauge H section steel have established the position as a standard beam material. Furthermore, in the spreading stage of light gauge H section steel in the steel-framed prefabricated houses, Nippon Steel & Sumitomo Metal played an influential role and has come to supply more than 80% owing to its quality and production capacity.

In addition to the features mentioned above, SMart BEAM is characterized by that both as-rolled specification and pre-coating specification types are producible by selecting the kind of steel strip to be used as the mother material. A hot-rolled steel strip sheet is used for the as-rolled-specified products and the products are used for the case where the all member materials are painted by customers after processing such as hole opening and welding. For the pre-coating-specified products, presently a hot-dip galvanized steel sheet (GI) is used as the mother material and the standard coating weight of GI is specified as Z27 (minimum total coating weight of both sides to be 275 g/m^2) that satisfies the Grade 3 provided in "The Law Pertaining to the Promotion of Securing of Quality of Houses (hereinafter referred to as Quality Securing Law)," which is classified as the highest in the deterioration countermeasure classification (assessment criteria: countermeasures to ensure durability of a structural frame for an approximate period of three generations (75–90 years)).

Pre-coating-specified SMart BEAM is used mainly for members of wooden prefabricated houses and small beams of wooden houses. In case SMart BEAM is used for wooden houses, materials are pre-coating specified in almost all cases for the purposes including compliance with the deterioration countermeasures (corrosion resistance) specified in the Quality Securing Law.

Intending for use in the field where the pre-coating-specified materials are used for members of wooden houses, Nippon Steel & Sumitomo Metal has developed and commercialized SMart BEAM™ termed as "SD-SMartBEAM™ (hereinafter referred to as SD-SMB™) that employs for the mother material the high corrosion resistance-coated steel sheet "SuperDyma™" as a means to further improve performance. SuperDyma has high corrosion resistance performance as compared with GI even if coating weight is reduced.

This article introduces the outline of the commercialized SD-SMB at first. Next, it introduces a part of the technological development made for the wooden house field, one of the areas of applications of SD-SMB (partial application of SMart BEAM to the area of large span parts where the use of wooden material is problematic).

2. Development and Commercialization of SD-SMartBEAM

2.1 Outline of merchandise of SD-SMartBEAM

The commercialized SD-SMB is the welded light gage H section steel of 400 N/mm^2 class that conforms to JIS G 3353 SWH400. In **Table 1**, the standard values of the mechanical properties of SD-SMB (SWH400) are shown. Furthermore, in **Table 2**, the type and the standard specification of the coating layer of SuperDyma steel strip that is used as the mother material are shown. The standard coating weight specification is as per K12. The welded portion of the flange and the web (hereinafter referred to as bead) and the flange edge are touch-up with water-soluble-type silver paint.

Listed as the merit of the SD-SMB over the GI specification is the possibility of reducing the coating weight with the effect of im-

Table 1 Mechanical properties of SD-SMB (SWH400)

Grade	Yield point or proof stress (N/mm²)	Tensile strength (N/mm²)	Elongation (%)		
			Material thickness (mm)	Test piece	Value
SWH400	245 min	400–510	≤5	JIS 5	23 min
			5<	JIS 1A	18 min

Table 2 Kind and the standard specification of the composed coated steel strips (SuperDyma)

Type of coating	Coating mass symbol	Minimum coating mass		Equivalent thickness of coating (mm)
		Average of 3 points (g/m²)	Minimum of 1 point (g/m²)	
Hot-dip zinc-aluminum-magnesium alloy coating	K12	120 (total in both sides)	102 (total in both sides)	0.033

proved corrosion resistance, thereby improving the workability such as welding. Furthermore, as the producible range of the steel strip of the mother material can be expanded by the SuperDyma treatment, increase in flange thickness from 6 mm of GI specification up to 9 mm is possible.

2.2 Development of SD-SMartBEAM

2.2.1 Features of SuperDyma

SuperDyma, which is used as the mother material of SD-SMB, is a hot-dip galvanized steel sheet developed by adding aluminum of 11 mass %, magnesium of 3 mass % and very small amount of silicon to zinc and its corrosion resistance has been improved greatly as compared with that of zinc-coated steel sheet.

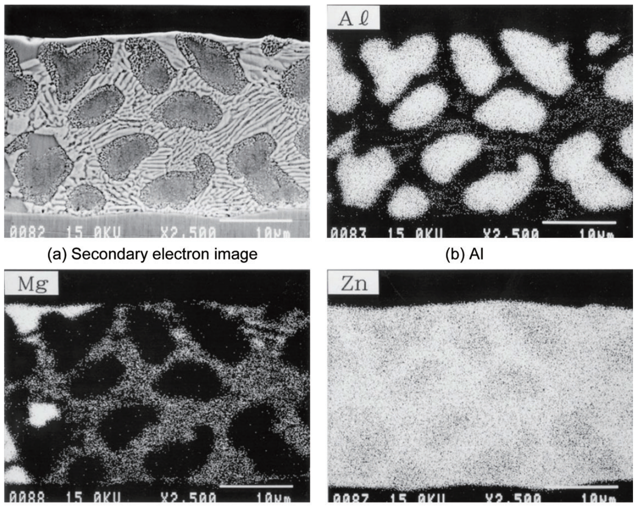
Owing to the addition of the abovementioned elements, Super Dyma has a characteristic coating layer structure. In **Fig. 2**, a sectional secondary electron image (SE) and the element distributions taken by an electron prove micro analyzer (EPMA) are shown. The coating solidification structure exhibits a primary crystal Al phase, a $MgZn_2$ intermetallic compound and a three-component eutectic structure of Al phase/Zn phase/$MgZn_2$.[1] High corrosion resist-ance of SuperDyma is considered to be attributed to the effect of the dense corrosion product containing Mg and Si. These corrosion products formed in the early stage of corrosion and covering the surface layer of the coating, acting as a protective coating.[2]

In **Fig. 3**, the quantity of the corrosion loss of bare SuperDyma in an outdoor exposure test is shown. SuperDyma exhibits the corrosion resistance about 3.8 times higher than that of the hot-dip galvanized steel sheet in a country environment and 5.1 times higher in the coastal and subtropical environments. From these results, the authorization by the special assessment method stipulated in the Housing Quality Assurance Act that SuperDyma has the corrosion resistance 3.8 times higher than that of GI has been obtained. Furthermore, along with the spread of high corrosion-resistant zinc-coated steel sheets, JIS G 3323 (Hot-dip zinc-aluminum-magnesium alloy-coated steel sheet and strip) was standardized in 2012 and Super Dyma has become a hot-dip zinc-coated steel sheet that conforms to the said JIS.

2.2.2 Assessment of corrosion resistance of SD-SMartBeam

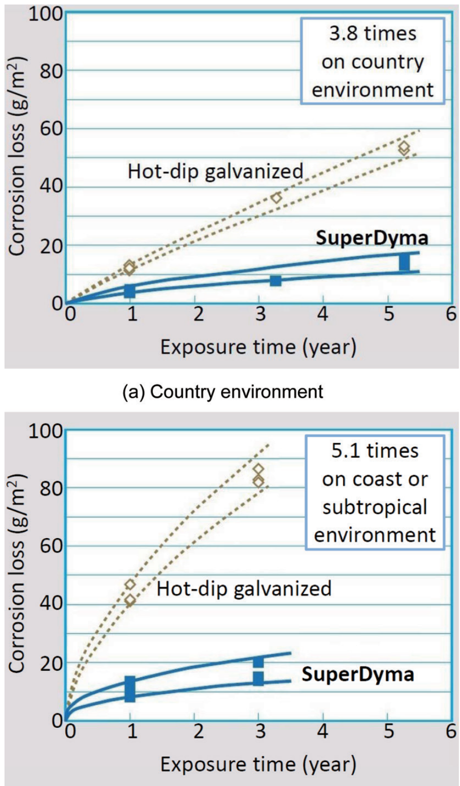
Although the mother material of SD-SMB is SuperDyma, coating does not exist at the bead part and the surface of the flange edge, therefore they need to be touch-up. Particularly, because the bead part where the flange and the web are welded is a crucial part for securing structure, proper touch-up depending on the purpose of usage is necessary.

Since the commercialized SD-SMB is mainly for use under an indoor environment, as for the method of the touch-up including



(a) Secondary electron image (b) Al
(c) Mg (d) Zn

Fig. 2 Section solidification structure of "SuperDyma"



(a) Country environment

(b) Coast or subtropical environment

Fig. 3 Quantity of corrosion in the outdoor exposure environment of "SuperDyma"

(Extracted from "Ministry of Land, Infrastructure, Transport and Tourism: Authorization Certificate as per Special Assessment Method: KOKUJUSEI No. 342 Certificate of Test Results") color tone adjustment, touch-up is provided using water-soluble silver color paint that contains aluminum flake. **Fig. 4** shows the appearance after the touch-up painting.

Upon commercialization, intended for confirmation of the corrosion resistance in the assumed use under an indoor environment, an acceleration test was conducted. Assuming a typical housing environment for in-door use, assessment test was conducted based on the JASO-CCT test (JASO-M609: composite cycle test provided by the Society of Automotive Engineers of Japan Inc. Standard, hereinafter referred to as JASO Test). The JASO Test is a test that repeats a plurality of a test cycle of 8 h test consisting of 5% salt water spray (2 h), holding in a dry state (4 h), and holding in a wet state (2 h), and it is said that, possibly as early as at about 45th cycle, red rust may start to appear on the sound part of Z27 (GI sheet with minimum total coating weight of front and back sides of 275 g/m^2), which is classified as durability grade 3 in the Quality Securing Law. Furthermore, in addition to the JASO Test, a neutral salt spray test (hereinafter referred to as SST) conforming to JIS Z 2371 and a wet-state test were performed for comparison purpose.

The specifications of the test pieces are shown in **Table 3**. An SD-SMB produced on an actual manufacturing line was cut to a short length of about 150 mm and cut in the center of the web and provided to the test in T shape. In order for the assessment to be made on a safety side, the coating weight of the SD-SMB was set as per K08 (minimum coating weight of both sides together is 80 g/m^2) that is less than the standard specification of K12. GI-SMB-Z27, which is a SMart BEAM currently produced using GI sheet as its mother material, was used for comparison.

Fig. 5 shows the appearances of the test pieces after 90th cycle of JASO test. Firstly, as for the general coated surface, contrarily to GI-SMB-Z27 where the partial generation of red rust is remarkably noticed on the web and the flange is almost entirely covered with white rust, in SD-SMB-K08, the area where white rust is generated is less and high corrosion resistance is confirmed. On the other hand, in the weld bead part where touch-up painting was applied, generation of certain amount of red rust was noticed on both test pieces and, consequently almost equal corrosion resistance performance was exhibited.

Table 4 shows the result of the assessment of the comparison with GI-SMB-Z27. It is confirmed that, as for general coated surface, even SD-SMB with K08 that has coating weight smaller than

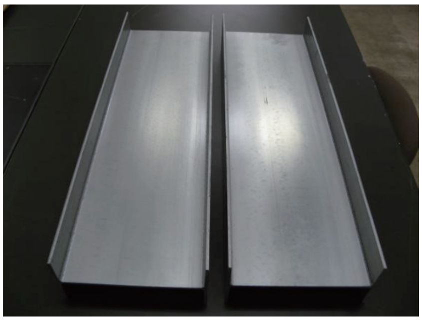
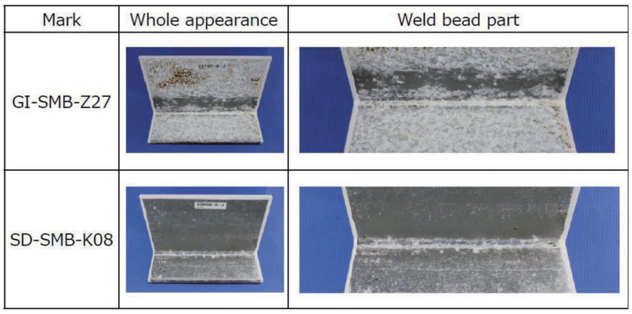
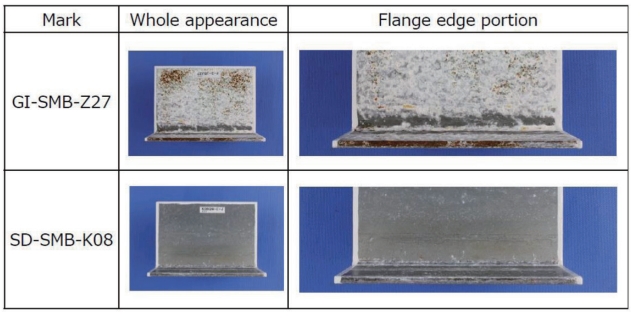


Fig. 4 Appearance of SD-SMartBEAM



(a) Weld bead part



(b) Flange edge portion

Fig. 5 Appearance after JASO-test (90 cyc)

Table 3 Test pieces for corrosion resistance evaluation

Mark	Coating type of composed steel strips	Thickness $t_w \times t_f$ (mm)	Coating mass symbol	Standard value of minimum coating mass (g/m^2)	Touch-up of the weld bead part
GI-SMB-Z27	Hot-dip galvanized	3.2 × 4.5	Z27	Average of 3 points (total in both sides) 275	Waterborne silver paint
SD-SMB-K08	SuperDyma	4.5 × 4.5	K08	Average of 3 points (total in both sides) 80	Waterborne silver paint

Table 4 Corrosion resistance evaluation result of "SD-SMartBEAM"

Mark	JASO 45 cyc			JASO 90 cyc			(Reference data)	
	Coated surface	Weld bead part	Flange edge portion (reference)	Coated surface	Weld bead part	Flange edge portion (reference)	Salt spray testing 960 h	Humidity cabinet test 1 000 h
SD-SMB-K08	○	○	○	◎	○	○	○	○

◎ : Better than GI-SMB-Z27 ○: Equal to GI-SMB-Z27 that of standard specification exhibits corrosion resistance higher than that of GI-SMB and, as for the touch-up painted sections of the bead and the flange edge, SD-SMB has corrosion resistance equal to that of GI-SMB-727.

3. Application of SMart BEAM to Wooden Structure Building and Assessment of Habitability under Vibratory Condition

3.1 Approach to wooden house field

In the field of wooden houses, which is one of the areas for application of SD-SMB, application to wooden buildings such as nursing and health care facilities for aged people is being developed, exploiting the extended portion of the current technology. A factor lying in the background is the incentive given by the administrative organizations that encourages the spread of wooden architectures. For instance, "The Law Pertaining to Promotion of Application of Wooden Materials to Public Architectural Sector" enacted in 2010, and the co-living of steel with wooden architectures including wooden houses has become an essential subject on the part of steel manufacturers.

Owing to the feeling of warmth, ease of processing and so on, wooden material is widely used in detached houses. However, in case a large span part is needed for instance like in wooden architectures represented by nursing and health care facilities for aged people that exceed in scale the conventional houses, and by houses each of which is partly used as a shop, it is also a matter of fact that the wooden material implies many problems like creep phenomenon (a phenomenon in which deformation progresses along with the elapse of long time, causing floor squeaking and the like) and the high cost brought up by complicated manufacturing process.

Taking into account the current situation of the wooden architectures and characteristics of wooden material, Nippon Steel & Sumitomo Metal is promoting technological development aiming at applying SMart BEAM to the large span part of the conventional wooden houses and wooden structures, and weaving of light gauge H section steel to "Frame Construction Method (2 × 4 construction method) Notification (Notification of Ministry of Land, Infrastructure, Transport and Tourism Nos. 1540 and 1541)."

As the first step of the technological development aiming at application of SMart BEAM to wooden structure field, jointly with a hardware manufacturer TATSUMI Corporation, "SMart BEAM construction method for wooden structures" using pre-coated SMart BEAM was developed as substitute for wooden secondary beams and the introduction of the method to market has just started.

3.2 About SMart BEAM construction method

As shown in **Fig. 6**, the SMart BEAM construction method is a method that bolt-joints a SMart BEAM with a primary beam of wooden material (glued laminated timber for structural use) or a wooden column using hardware. To more than half of the present wooden structures, a hardware construction method that connects members with hardware and bolts is applied; therefore, consistency of the hardware in detail needs to be maintained. Then, the construction method was jointly developed with TATSUMI, the largest company specializing in wood-hardware construction method. It is a construction method devised to employ SMart BEAM only to secondary beams of a large span part and roof beams, leaving other wooden structures as conventionally structured. Applied usage is for a house with its large span part over the first floor space used as a shop or, for the dining room section of nursing and health care facilities for aged people. Furthermore, the SMart BEAM construction method has acquired the assessment of the Building Center of Japan (a general incorporated foundation), and by conducting designing following the assessment, practical work like submission of application for building confirmation of small scale wooden structure termed as No. 4 category architectural structure is eased. **Fig. 7** shows an example of the actual application of SMart BEAM.

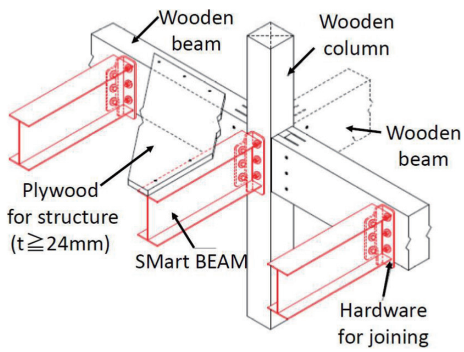


Fig. 6 Joint system of "SMart BEAM" construction method

Fig. 7 Application case of "SMart BEAM" construction method

3.3 Vibratory property in SMart BEAM construction method

In developing and expanding the application range of the SMart BEAM construction method, securing of habitability under a vibratory condition is a big technical subject. Stated in this section are the verification of the performance of the present SMart BEAM construction method, and the assessment of the habitability and the study on countermeasures for securing habitability, both conducted aiming at expanding application range.

3.3.1 Method of assessing habitability and performance-deteriorating factor in large span part

The assessment of habitability under a vibratory condition is to be conducted in terms of the index *VI(2)* stipulated in the guideline of the Architectural Institute of Japan.[3)] *VI(2)* is expressed by Formula (1) and shows that the smaller the value is, the higher the performance becomes. In the formula,

D_{max}: Maximum displacement of floor

V_m: The value of D_{max} divided by T_m, the time from the start of vibration to the arrival of maximum displacement

T_h: Time required for the amplitude of acceleration of floor to be dampened to 14.1 cm/s^2

$$VI(2) = 0.2\log D_{max} + 0.5\log V_m + \log T_h \quad (1)$$

From the formula, it is known that in order to enhance the performance in the subject assessment, it is necessary to reduce the maximum displacement and the speed at which the maximum displacement is reached and to dampen the acceleration early. Quite contrarily, when a floor span part is enlarged, the habitability under

Table 5 Test body

Test body		Floor		Beam	Wooden girder section (mm)
No.	Name	Span (mm)	Width (mm)	Material / section (mm)	
1	6P-W	5460	3640	Glue laminate timber / 105 × 330	105 × 360
2	6P-SMB	5460	3640	SMB / 300 × 100 × 3.2 × 3.2	105 × 360
3	8P-SMB	7280	7280	SMB / 400 × 135 × 4.5 × 6.0	105 × 240

Fig. 8 Test body No.3 (look up from lower level)

a vibratory condition tends to deteriorate generally due to reasons that "dynamic maximum displacement D_{max} increases similarly to static displacement and furthermore, V_m, the function of D_{max}, also increases," and "the natural frequency of the floor falls, and the floor becomes prone to resonate with the vibration caused by the behaviors of dwellers like walking."

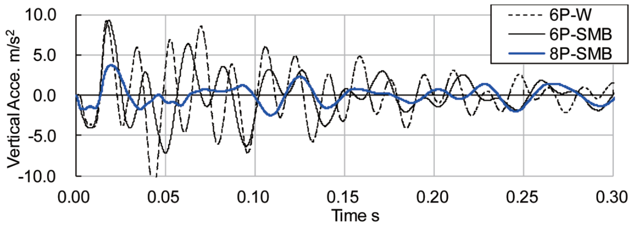
Taking into account the above, the habitability under a vibratory condition when the SMart BEAM construction method is applied to a large span part is assessed by an experiment as stated in the following section.

3.3.2 Assessment of experiment for habitability under vibratory condition

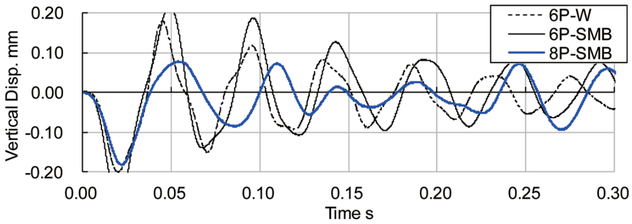
In **Table 5**, the specification of the subject, three test bodies, for assessment is shown. Also in **Fig. 8**, as an example of the three test bodies, the view of the lower side of the test body 3 looked up at from below is shown. Furthermore, although from the viewpoint of rust prevention, pre-coated SMart BEAM is used for beams as the final merchandize in the SMart BEAM construction method, red coating for simple rust prevention is used in the test.

The test body 1 is simulated for general wooden floor and is equipped with sufficient habitability under a vibratory condition and made to be the standard test body in the experiment. In the test bodies 1 and 2, a large span of 5460 mm, which is generally seen in houses is assumed, and for the beam (the word "beam" mentions secondary beams exactly, which hereinafter referred to simply as beam), glued laminated timber is used in the test body 1 and SMart BEAM is used in the test body 2. The span of the test body 3 is 7280 mm assumed for the large span part in large-scale houses and wooden architectures and SMart BEAM is used for the beam. The sectional dimensions of the beams have been selected so as to control the deflection to below about 1/600 (9.1 mm) in the test body 1 and the test body 2.

On the other hand, in the test body 3, in order to avoid the aforementioned deterioration in habitability under a vibratory condition, a section relatively higher in rigidity has been selected so as to control the deflection to below 1/1120 (6.5 mm). In the test bodies where SMart BEAM is used for the beam, the floor material of plywood of 24 mm in thickness is connected to the beam with self-drill screws. The beams (secondary beams) of the test bodies are connected to the outer peripheral beams (primary beams) with bearing bolts via hardware. Furthermore, the beams are arranged at the separation distance of 910 mm in the width direction.



(a) Vertical acceleration response



(b) Vertical displacement response

Fig. 9 Time history responses result of acceleration and displacement

Excitation and the measurement are conducted at the center position in the span direction and in the width direction of the floor. For the excitation, in order to simulate a dweller walking on the floor, a lump of clay of 3 kg was free-dropped from the height of 400 mm. The vibration was measured, taking the upward direction of the vertical axis as positive, by an acceleration-measuring meter and a laser-type displacement-measuring meter installed on the web axis position of the lower flange of the beam.

Fig. 9 shows the results of the measurement of the timewise responses of acceleration and displacement of the three test bodies. When the results of the test body 1 and the test body 2 are compared, it is found that the factors that influence the assessment of habitability under a vibratory condition, namely the maximum displacement, the speed at which the vibration reaches its maximum displacement, and the damping time of the acceleration exhibit almost similar values. Although the assessment of the habitability using the absolute numerical values is difficult since the excitation is provided for a simulation purpose in the experiment, however, when relatively assessed, it is judged that the test body 1 and the test body 2 exhibit almost equivalent habitability. On the other hand, the test body 3 exhibits values of the maximum displacement and the maximum acceleration speed smaller than those of other test bodies and it is considered that, as aforementioned, the effect of using a beam with rigidity higher than those of other test bodies has been obtained. However, both in acceleration and in displacement, the phenomenon of the amplitude growing smaller once and then growing larger, “beats” were observed.

Here, beat, a terminology in physics, is a phenomenon in which a composed wave is produced by two waves having slightly different frequencies and interfering with each other and the amplitude is slowly and periodically changes. For reference, in **Fig. 10**, two sinusoidal waves of amplitude 1 with the frequencies of 20 and 22 Hz and a composed wave produced thereby are shown. From the figure, it is found that a composed wave having a beat of 1 Hz (half of the difference of the frequencies of the two sinusoidal waves) is produced.

In **Table 6**, the result of the assessment in terms of aforementioned *VI(2)* is shown. Likewise, the observation result of the timewise response, the test body 1 and the test body 2 are assessed to have almost equal habitability. On the other hand, in the test body 3, as compared with the test body 1 and the test body 2, habitability is deteriorated as the damping time of acceleration is becoming longer, which is considered to be due to the influence of the beat, despite that the maximum displacement has become smaller owing to the effect of high stiffness of the beam.

In order to grasp the beat that deteriorates habitability, analysis of the vibration characteristics of the test body 3 was conducted. In **Fig. 11**, the result of Fast fourier transform (FFT) analysis of the acceleration response of the test body 3 is shown. From the figure, it is known that the test body 3 has its response peaks at the frequencies of 16.4, 20.0, 28.2, and 38.2Hz. Beat is considered to be produced in the test body 3 by the existence of a plurality of vibration modes in a narrow-ranged frequency band.

Furthermore, in **Fig. 12**, as a result of mode analysis of the experiment, the mode pattern of the floor near the peak frequency in Fig. 11 is shown. The mode analysis of the experiment is conducted in the range of 1/4 of the test body taking into consideration the symmetry of the plane. The left to right direction in the figure shows the direction of the span and the ○ mark at the bottom right on the mode pattern represents the center point. The pattern is represented as a contour pattern of standardized mode vector with the maximum amplitude taken as 1. Furthermore, the dotted line in the figure represents the wooden primary beam part of the outer peripheral of the test body. From the figure, it is found that the test body 3 vibrates in the neighborhood of the aforementioned frequencies, having the antinode at the floor center section, in a manner to grow to higher-order vibration in the direction perpendicular to the direction of the span (width direction) to increase the number of antinode of vibration.

3.3.3 Analysis of beam vibration characteristic

In order to grasp the beat, a numerical analysis is conducted based on the result of the mode analysis of the experiment reported in the previous section, and the vibration characteristic of the beam is analyzed.

For the analysis, an all-purpose software ANSYS was used and shell elements were applied to both of the floor material and the beam. Furthermore, the analysis was made for the entire floor. In **Fig. 13**, the vibration mode pattern forms of the floor and the beams as a result of the analysis of vibration eigenvalues are shown. Likewise, Fig. 12, the pattern is represented as a contour pattern of standardized mode vector with the maximum amplitude taken as 1. Furthermore, from Fig. 13, it is found that, when the results of the numerical analysis (a)–(d) are compared with the results of the experiment in Fig. 12 (a)–(d), although discrepancies in the frequency by about 10% at highest exist, the vibration mode form is well reproduced. Furthermore, it is found from Fig. 13 that, as the upper displacement of flange of the SMart BEAM is restrained by the floor material whereas the lower flange is not restrained, it is known that some beams vibrate, being twisted in the axial direction of the member. As the torsional vibration of the beam is produced independently in each beam, when the floor span part and the number of the beam installed in the width direction becomes larger, a plurality of vibration modes having almost same frequencies are produced. It is presumed that the beat is produced by the response of the floor, and therefore, for the elimination of the beat, suppression of the torsion-

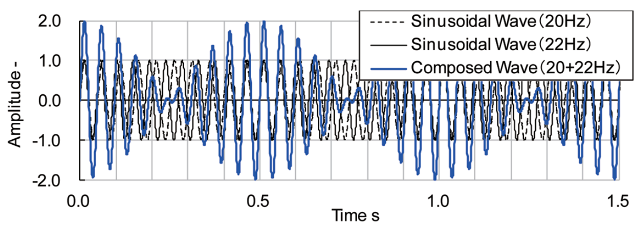


Fig. 10 Beat of composed wave caused by 2 waves in narrow-ranged frequency-band

Table 6 Evaluation result of *VI(2)*

Test body No.	Test body Name	D_{max} (mm)	V_m (mm/s)	T_h (s)	*VI(2)*
1	6P-W	0.201	9.98	1.258	−0.240
2	6P-SMB	0.262	13.53	1.114	−0.204
3	8P-SMB	0.183	8.36	1.842	−0.121
-	8P-C.M.ed	0.051	2.18	0.794	−0.890

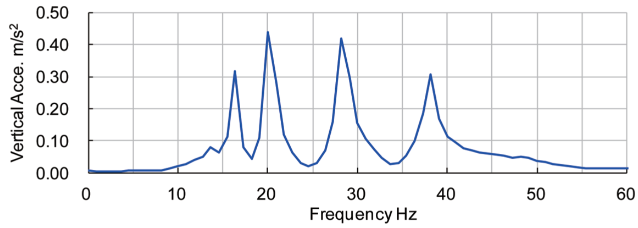
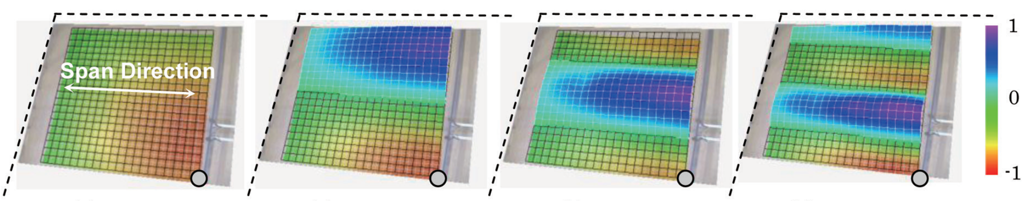


Fig. 11 Result of FFT analysis of the acceleration response



(a) 16.6Hz (b) 20.4Hz (c) 29.0Hz (d) 38.8Hz

Fig. 12 Vibration mode of the floor

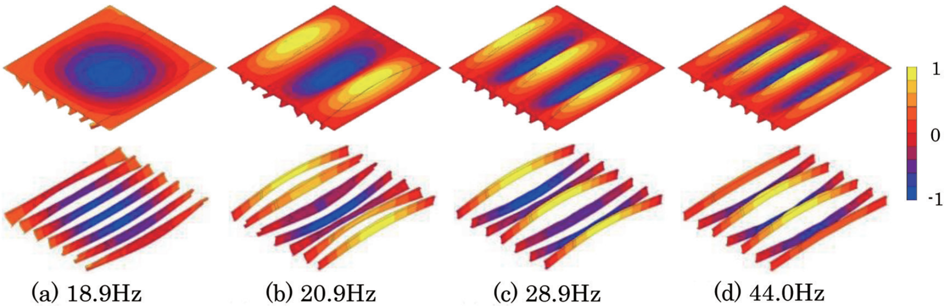


Fig. 13 Vibration mode of the floor and the beams (Upper: floor and beams are shown, Lower: only beams are shown)

Fig. 14 Test body after the countermeasure

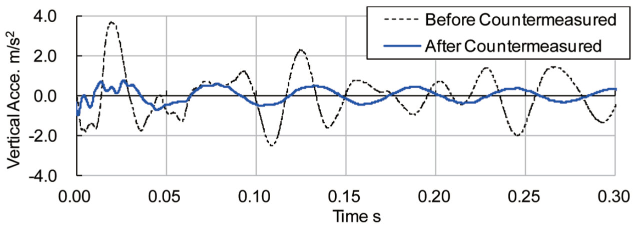


Fig. 15 Comparison of the acceleration responses before and after the countermeasure

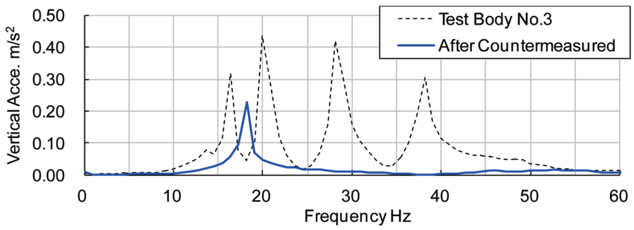


Fig. 16 Comparison of the FFT analysis results before and after the countermeasure

al vibration of the beam is necessary.

3.3.4 Example of countermeasures for improving habitability under vibratory condition

As an example of countermeasures for suppressing beat and improving the habitability under a vibratory condition for the case of the large span part of about 7.2 m, partial arrangement of beams in lattice pattern was contemplated. In **Fig. 14**, the countermeasure applied to the aforementioned test body 3 is shown. Furthermore, shown in **Fig. 15** is the comparison of before and after of the application of the countermeasure with respect to the timewise response of acceleration excited by the clay lump. From the figure, it is found that, with the partial application of the lattice-arranged beams, the acceleration response is dampened at an early stage. Furthermore, as **Fig. 16** shows that the vibration modes are converging to one mode after the countermeasure is taken, it is found that the frequency modes that existed in a narrow-ranged frequency band and caused beat have been eliminated. Also *VI(2)* value has come to −0.890, and as found in the previously shown Table 6, the habitability under a vibratory condition has been improved to above that of the wooden beam floor.

4. Conclusion

This article introduced the product development of "highly corrosion-resistant pre-coated welded light gauge H section steel (SD-SMartBEAM)" and the technological development for the application to the field of large span parts of wooden structures that is considered to be promising as a market where the pre-coated light gauge H section steel are utilized. Hence, Nippon Steel & Sumitomo Metal will continue to make efforts to further improve the performance of SD-SMartBEAM, to expand the field of application, and to promote the use of SD-SMartBEAM in a wider range including the field of wooden structures by exploiting the technological development.

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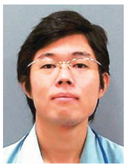
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