GLOBAL NON-BALLASTED RAIL FASTENER DEVELOPMENT BASE ON TAIWAN EXPERIENCE

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Abstract: Taiwan has been active in construction new railway system in recent years and, furthermore, several old railway systems are undergoing overhaul. The trackwork engineering will be one of the major key to decide whether the railway was successful or not, Now-a-day, All the railway systems in the world are concentrating on improving the trackwork system being a safety, longer service life, low maintenance, low environmental pollution. The international track work field was concentrating on the development of non-ballasted (Direct Fixation) track, because it highly automatic efficient and low maintenance. This paper was study the Taiwan non-ballasted (Direct Fixation) track rail fastener (DFF) experience and it's localized production and development, and the DFF experience of other railway systems.

This paper was base on the accurately experience and achievement of Taipei mass rapid transit system (TRTS) to study the DFF, This paper was specially point out the DFF test plan and the acceptance criteria, it was base on the TRTS character and the simulation of accurate operation that conclusion was discuss among TRTS, Chung San Institute of Science Technology, Industrial Technology search Institute.

We hope that our direct fixation rail fastener experiences, special in the test plan, can share with other railway systems. This experience can help the future development of non-ballasted track and DFF.

Key words: non-ballasted track, ballasted track, direct fixation rail fastener (DFF), insert loss, fail-safe.

Ⅰ. Introduction

All kinds of track systems have developed and can be categorized from three aspects: Geographic region, technology of the system, and the way of service. [13]

In Taiwan, it is essential to construct a high-capacity railway system that was depending on the needs of local people; a unique plan should be made for each area. In addition, since each place has different current condition and degree of urgency, priority should be assigned. Among these, Taipei metropolitan area is on the top of list. Since initial planning in 1984 to now, Mucha line, Tamshui line, Chungho line, Hsintien line and Nankung-Pancho partial section line have already been finished. Furthermore, inter-city rail system is also in progress. More than that, it has been awarded by B.O.T. in 1998 for high- speed rail, and is moving into the stage of construction. Beside, light rail system is in the evaluation stage in some counties.

The technique of track system in Taiwan has been improved by searching information worldwide. By focused on Taiwan's experience of the construction of resilient rail fastener system on non-ballasted track, and with the trend of W.T.O., this essay will discuss "The structure of specification for the direct fixation track's rail fastener ". Thus, it can be used as a reference for other researchers to develop the system further.

II the Modern Track Elements Tree and Relevant International Standard Development [13]

1. Rail

That's the main element to directly support the EMU's wheel, Taipei mass rapid system (TRTS) was used the joint-less continuous welding rail (CWR).

2. Rail fasteners [13]

The rail fastens was divided to three parts:

─CLIP: CLIP, CLIP insulator.
─Base-plate: rail pad, rail base-plate.
─Anchorage: anchor insert, anchor blots.

A. CLIP: CLIP, CLIP insulator.

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Its' design shall base on the followings items:

a. Maintain the track gauge,
b. Absorb the impact and vibration and reduce the noise,
c. Keep fastener components in the same service life,
d. Ease to install, to replace and to maintain,
e. Being a good electric insulation and environmental resistance.

B. Base-plate: rail pad, rail base-plate

Its' design shall base on the following items:

a. Rail size and wheel load
b. Maintain the track gauge
c. Restrict rail movement within safety allowance (three directions)
d. Transmit the EMU's load uniformly
e. Absorb the vibration and reduce the noise
f. Free maintenance, good electric resistance and environmental resistance.

C. Anchorage: anchor insert, anchor bolt

a. Keep the rail in the correct position
b. Being a good electric resistance and environment resistance.

The whole fasteners should avoid the same nature frequency of the EMU, and to absorb the interaction between EMU and track / structure (especially for the direct fixation track), and all put into economic evaluation.

3. Track support system: Ballasted and non-ballasted and ballast-less track.

III the Modern Track Planning Evaluation & Work Process and The Scope Involved

The section two already explains the basic design concept for track components, and the following section will further study to direct fixation rail fastener.

1. The modern track planning merit [1]

A. Reduction of initial investment cost plus maintenance cost,
B. Take care for necessary function,
C. Take care for noise and vibration,
D. Take care for rail corrugation.

High-level fastener is used to reduce noise and vibration in Japan but the probability of rail corrugation generation at such fastener section is very high, rail-grinding system is necessary for high-level fastener track.

2. The modern track planning process [1]

The track planning is a system approach, the steps are

A. The objective and requirement of the track,
B. Alternatives of support system,
C. Noise and vibration attenuation of the track,
D. The bonded base-plate adaptability and localization (if necessary),
E. The selection and modify design for track prototype (localize the track prototype),
F. Construction operation and feedback process.

3. The modern track planning scope [1]

The track planning is a system-wide involve the process are

A. Environmental evaluation,
B. System-wide analysis and then to define track character,
C. Fasteners' structure analysis,
D. Economic evaluation at different stage.

Ⅳ The Design Main Requirements Of Direct Fixation Rail Fastener

Rail and support system is top and bottom element of track, fastener is an interface element in between, and the design requirements are following:

1. Cost saving [1] [5]

Compromise with concrete bed of plinth is a key related element for fastener design. If plinth is necessary adjustment 10 mm, then fastener should have 10 mm to adjustment. If plinth is necessary adjustment 20 mm, then fastener should have 20 mm to adjustment and Provide different suitable type match for different loading and Easy replacement.

2. Performance of a fastener

To have sufficient strength and reasonable life time, To fix rail and fasten rail resistant vertical/ horizontal force and rail creeping, To mitigate and absorb impact and vibration, To allow longitudinal sliding of rail and have enough electric resistance, To have adjusting alliance of track irregularity and absorb the different movement between track and structure.

3. To verify the special requirement of fastener

The pad can absorbs and reduces vibration, the clip pushes rail in order to follow action of a pad and allow rail to slip at force, and the compressed pad resists rail creeping.

Ⅴ. The History and Development and Production Experience of Resilient Rail Fastener in Taiwan

Both of TRTS and TRA have been used the direct fixation track in Taiwan since 1990, the TRTS (Taipei Rapid Transit System) detail was as following:

The Mass Transit Systems at Taipei was design by ATC (America Transit Company), they used the direct fixation fastener (DFF) at elevated and tunnel section, TRTS have been selected the

Lord DFF for Tamshui line and Chungho line, the ATS DFF for Hsintien line, Nankang line and Pancho line.

A. Lord DFF

a. Sandwich base-plate (top and bottom plate was metal, middle layer was elastomer pad, fully bonded with vulcanization).

b. Spring coefficient [28]: 15.76 kN/mm (±10%) for underground section
20.38 kN/mm (±10%) for elevated section.

c. Anchor bolt only through bottom plate.

d. Top plate cast-in down and bottom plate cast-in up act like an inner snubber.

B. ATS

a. Sandwich Base-plate (top and bottom plate was metal, middle layer was elastomer pad, fully bonded with vulcanization).

b. Spring coefficient: 15.76kN/mm (±10%) for underground [28].

c. Anchor bolt only through bottom plate.

d. Top plate and bottom plate is wave shape overlapping.

Taiwan manufacturer with the international cooperation produced the ATS rail fastener.

TRTS have been studying the several types of DFF (including Lord, ATS, and Getzner) for nature frequency resonance and insert loss for rail corrugation and environment consideration.

Ⅵ The Localize Acceptance Criteria and Test Plan Guideline Development

1. Test plan in U.S.A

A. Previous test plan (see the figure 1)

B. Current test plan (see the figure 2)

TRTS DFF is following the American design concept, so our test plan was based on the American test plan.

2. TRTS DFF test plan

A. Stage 1: CT501 trackwork contract

CT501 specification was the first contract of TRTS; we only set up our system parameter and functional requirements, and ask our contractor has to set up a test plan basic on our system characteristic. The contractor proposed the test plan, in according to the supplier's proposal.

B. Stage 2: CH521, CN531 and CP541 contract

We have been learned a lot of experience by our effort, so we have enough technology to identify DFF test plan guideline by the following process, the guideline were including the following items:

a. To get the American DFF test plan being the basic test plan framework.

b. To defined the environmental factor for the corrosion test.

c. To add the "fail safe " requirement into the test plan.

C. Stage 3: CD511 contract

We revised the DFF test plan in new track work specification (CD511 contract) for approaching more reality, the modification of DFF test plan was based on that the discussion among TRTS, Chung San Institute of Science Technology, Industrial Technology search Institute and DFF's supplier. The test process was accurately to simulate the real service situation of DFF in the only one sequential procedure. The testing sequence was as following

-Qualification testing sequence [28]

This qualification test was verified whether the DFF meet the origin system characters and contract's requirements, it can also cooperate with other interface systems requirement, such as wheel and track interaction, the smoothness of track plinth surface…etc.

The DFF qualification tests shall be selected and performed on a group of four fasteners in accordance with the followings tests (as show loading per one fastener). For mechanic tests, tests shall be performed on a group of four fasteners per 25.4mm space each other, in which all fastener shall be shimmed 20mm in according with configuration requirements and the outside two fasteners shall be shimmed 2mm additionally to simulate the adjacent fasteners elevation deviation.

a. Voltage withstand test：

This test was verified whether the DFF could keep normal functional workability after it took high voltage for a long time.

Acceptance criteria ：The elastomer shall withstand this with no visible damage such as splits, cracks, pinholes, or factures. There shall be no evidence of arcing, arc tracking, or other voltage breakdown.

b. Electrical resistance and impedance test：

This test was verified the DFF electrical isolation, to reduce the amount of stray current and to avoid electrical corrosion damage.

Acceptance criteria ：The Minimum resistance for electrical resistance test shall be 10MΩ when dry and 1 MΩ when wet. The minimum impedance for electrical impedance test shall be 10KΩ.

c. Dynamic to static stiffness ratio test：

This test was verified the DFF stiffness didn't have big difference between dynamic and static condition, The DFF have a stable elastic stiffness. Vertical down load 17.8-35.6kN.

Acceptance criteria：The Dynamic to static stiffness ratio shall not exceed 1.5 between 17.8kN and 35.6kN.

d. Vertical load test：

This test was verified the whole DFF body stiffness, to know the functional range of reduce noise and vibration. Maximum Vertical down load 68.5kN.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture. The stiffness shall be 15.76kN/mm±15 ％ between 0.4 and 3.2mm.

e. Vertical uplift test：

This test was verified the whole DFF body stiffness under uplift force (10.7 kN) and compression down load (10.7kN) situation, wasn't big difference still in the allowable range.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture. The vertical deflection of the fastener for an upward load of 8.9kN shall be within 135 ％ of the deflection for the 8.9kN downward vertical load. After removal of load within two minutes, the residual deflection of rail shall not exceed 0.127mm.

f. Lateral load test：

This test was verified that the railhead deflection shouldn't too big and get track gauge too wide when the DFF was taken lateral load (At gauge side 26.2kN) and Vertical down load (46.9kN).

Acceptance criteria ： The fastener components shall be no evidence of failure by slippage, yielding, or facture. The maximum lateral deflection of the railhead shall not exceed 7.62mm. After removal of load within one minute, the residual lateral deflection of railhead shall not exceed 1.575mm.

g. Lateral restraint test：

This test was verified whether the DFF has enough lateral restraint ability that it could restraint outer lateral load (At gauge side 26.2kN along rail base).

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture. The maximum lateral deflection of the rail shall not exceed 3.175mm. After removal of load within one minute, the residual lateral deflection of rail shall not exceed 1.575mm.

h. Longitudinal restraint test：

This test was verified whether the DFF has enough longitudinal restraint ability that it could resistant outer longitudinal load.

Acceptance criteria：Except as the slippage between rail and fastener, The fastener components shall be no evidence of failure by slippage, yielding, or facture. The longitudinal load versus deflection curve shall lie entirely in the envelope of original design rang. After removal of load within one minute, the difference between the original and final positions of rail shall not exceed 3.175mm plus the slippage distance of the rail.

I. Vertical and lateral repeated load test：

This test was simulating dynamic train operation, whether the DFF could still normally workable under the dynamic load of train. 3million cycles. Vertical down load 46.9kN, gauge side lateral load 15.4 kN, vertical up load 4.1kNand field side lateral load 4.6 kN shall constitute one cycle.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture.

j. Corrosion test：

This test was simulating accurately environment condition, whether the DFF could still normally workable under this environment condition. ASTM B117, Minimum 1000hrs.

Acceptance criteria：After Complete of test, the condition of the metal surfaces shall match or be superior to Grade 8 (scratch area per ASTM D1654 Procedure A and the other areas per ASTM D610)

k. Heat aging test：

This test used heating process to accelerate the DFF aging procedure then verified whether the DFF could still normally workable. (Neoprene based elastomer shall be aged for 70hr at 100^0C and natural rubber based elastomer shall be aged for 336hr at 70^0C in according with ASTM D573)

Acceptance criteria ： This is a condition process and there is no acceptance criteria.

L. Push-pull test：

This test was simulating the repeating recycle process of the DFF maximum predictable longitudinal deflection in the whole service life, whether the DFF could still normally workable under the maximum longitudinal deflection.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture. Clip shall be no evidence of sliding out or backing out of its hold-down housing more than 1.588mm.

m. Vertical and lateral repeated load test：

This test was simulating dynamic train operation after certain service period, that the DFF could still normally workable under the dynamic load of train.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, or facture.

n. Vertical uplift repeated load test：

This test was simulating DFF body under uplift force (4.1kN) and compression down (46.9kN) load situation after certain service period (2 million cycles), that the DFF could still normally workable.

Acceptance criteria ： The Fastener components shall be no evidence of failure by slippage, yielding, abrasion, or facture. The residual deflection shall not exceed 0.127mm.

o. Vertical load test：

This test was verified the whole DFF body stiffness after certain service period, whether the DFF stiffness still in the allowable range. 2million cycles. Vertical down load 46.9kN and up load 4.1kN shall constitute one cycle.

Acceptance criteria ：After performance of fatigue tests, the stiffness shall be within 15％ of the initial test values.

p. Vertical uplift test：

This test was verified the DFF uplift function after certain service period that its function changes still in the allowable range.

Acceptance criteria ：After performance of fatigue tests, the ratio of vertical deflection shall be within 15％ of the initial test values.

q. Lateral load test：

This test was verified the DFF had been used after certain service period that the railhead deflection shouldn't too big and get track gauge too wide when the DFF was taken lateral load.

Acceptance criteria ：After performance of fatigue tests, the maximum lateral deflection of railhead shall be within 15％ of the initial test values.

r. Lateral restraint test：

This test was verified the DFF had been used after certain service period that the DFF still has enough lateral restraint ability when the DFF was taken lateral load.

Acceptance criteria ：After performance of fatigue tests, the maximum lateral deflection of railhead shall be within 15％ of the initial test values.

s. Longitudinal restraint test：

This test was verified the DFF had been used after certain service period that the DFF still has enough longitudinal restraint ability when the DFF was taken longitudinal load.

Acceptance criteria ：After performance of fatigue tests, longitudinal restraint shall be within 15％ of the initial test values.

t. Dynamic to static stiffness ratio test：

This test was verified the DFF had been used after certain service period that the DFF could still normally workable when the DFF was under the dynamic load of train.

Acceptance criteria ：After performance of fatigue tests, the dynamic to static stiffness ratio shall be within 15％ of the initial test values.

u. Electrical resistance and impedance test：

This test was verified the DFF had been used after certain service period that the DFF still have enough electrical isolation, to reduce the amount of stray current and to avoid electrical corrosion damage.

Acceptance criteria ：After performance of fatigue tests, the electric resistance and impedance shall be within 15％ of the initial test values.

v. Voltage withstands test.

This test was verified the DFF had been used after certain service period that the DFF could still keep normal functional workability after it took high voltage for a long time.

Acceptance criteria ：The elastomer shall withstand this with no visible damage such as splits, cracks, pinholes, or factures. There shall be no evidence of arcing, arc tracking, or other voltage breakdown.

-Production Quality Testing Sequence [28]

The Production quality testing sequence was supervised that the routine products could keep a good quality to meet the contract's requirements, The test items were selected in qualification test, The method and acceptance criteria was same as the qualification test, so we wouldn't make any further description of this section.

a. Voltage withstand test,
b. Electrical resistance and impedance test,
c. Dynamic to static stiffness ratio test,
d. Vertical load test,
e. Vertical uplift test,

f. Lateral load test,

g. Lateral restraint test,

h. Longitudinal restraint test,

i. Vertical and lateral repeated load test.

j. Stage 4: For the future contract

There are rail corrugation, noise and vibration problems during the Tamshui (CT501) line operation from Feb. 28, 1997 till now, 2.5 years or sol, so we studying all the possible causes and solutions. There are some fours we reconsideration for DFF's potential requirements::

a. To define the DFF's track nature frequency.

b. To define the DFF's damping ratio.

c. To avoid the same nature frequency with car body (TRTS bogie's nature frequency is 40 Hz for vertical direction).

d. To compare the DFF's insert loss cooperate.

We think the four issues will push us to identify the worldwide integration specification in near future.

Ⅶ. Conclusion and Suggestion

Since the direction fixation track maintenance free and stables structure, it will be widely use in the world. Even they have different type of direction fixation track that they were based on different type of railway systems (such as high speed railway system, mass rapid transit system, traditional railway system, light railway system). But they still have the same principle of design, subject to the direction fixation track fixed on rigid support; the design requirements should be based on the following items:

a. To analyze track and elevated structure interaction,

b. To analyze wheel load distribution,

c. To analyze environmental affection,

d. . To carry on the fail safe design,

e. To analyze the DFF insert loss (for reducing the noise and vibration in the track),

f. To avoid the same nature frequency between track structure and car body,

g. To analyze the suitable stiffness and damping ratio,

h. To set up a proper test plan (both pre-qualification test and production test) that can be qualify the DFF.

We hope that direct fixation rail fastener experiences of the Taipei mass rapid system, special in the test plan, can share with other railway systems. In the same time, the other railway systems can share with their direct fixation rail fastener experiences, and then all of us can improve our railway track systems in the future.

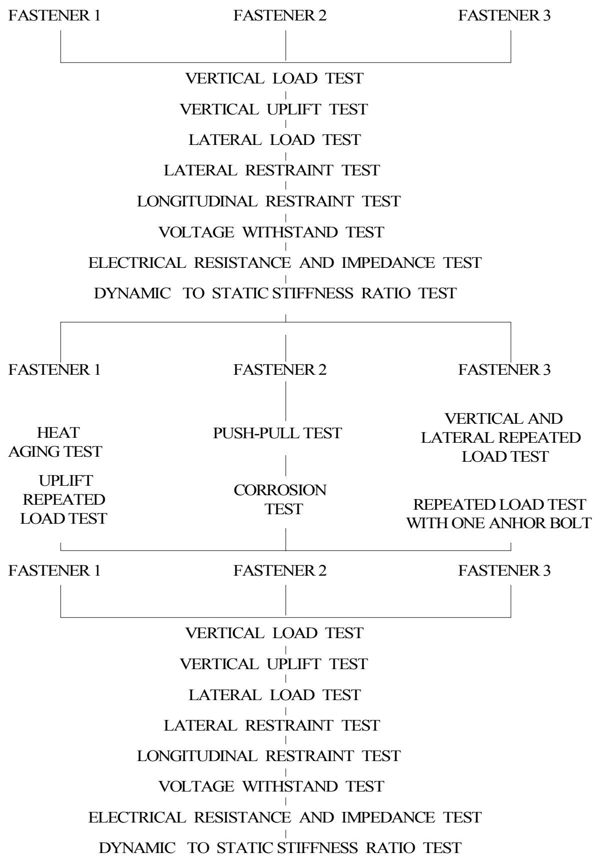

FIGURE 1 Previous test plan in USA

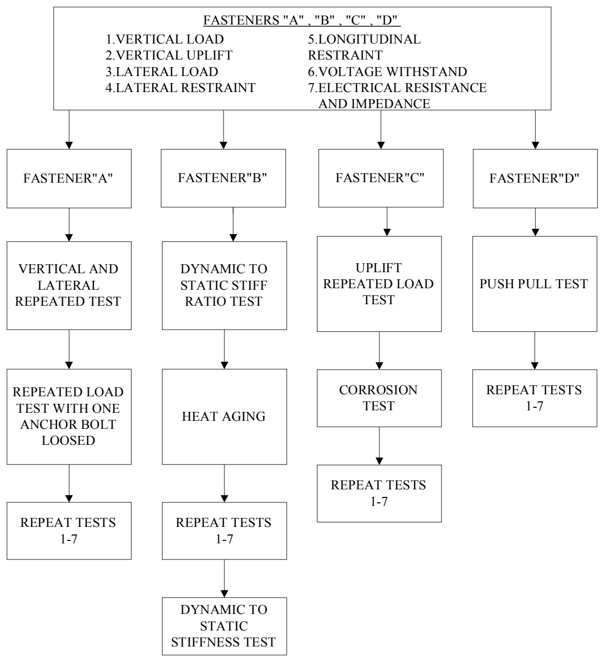

FIGURE 2 current test plans in USA

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