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碩士論文

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master thesis

# 軌道缺陷檢測系統

# Railroad Defect Inspection System

林衛成

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# 摘 要

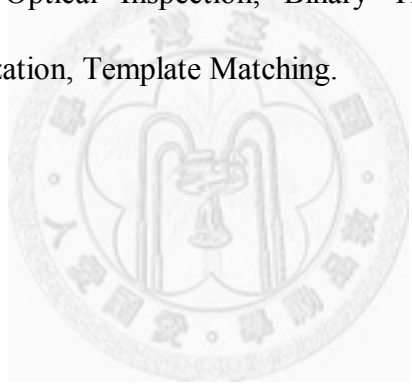
本論文是關於將影像處理的技術應用在大眾運輸系統之軌道檢測的實作，使用的演算法包括了二值化、型態學、直方圖等化與模板比對等。另外，針對較特殊的檢測需求，設計對應的檢測演算法。最後將方法整合實作成完整的檢測邏輯。

關鍵字：自動光學檢測、二值化、型態學處理、直方圖等化、模板比對

# Abstract

This thesis presents an implementation of inspecting railroads of Mass Rapid Transit by image processing which includes binary thresholding, morphology, histogram equalization, and template matching. Furthermore, we design specific algorithms to handle specific inspection objectives. Finally, we integrate all methods into complete inspection logic.

Keywords: Automatically Optical Inspection, Binary Thresholding, Morphological Filtering, Histogram Equalization, Template Matching.



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# Chapter 1 Introduction

Nowadays, Mass Rapid Transit (MRT) has become an essential part of the transport network in Taipei City. To maintain the performance and ensure the safety of MRT, a railroad inspection system is indispensable.

Moreover, Automatic Optical Inspection (AOI) systems are very common in modern industry. AOI systems inspect products by computer program instead of manpower and therefore provide various advantages such as higher productivity, higher efficiency, higher accuracy, and lower cost. We can implement an AOI-like system to help us inspect MRT railroad too. This system can keep most merits of AOI systems and has flexibility to deal with various inspection requirements.

Our objective is to design an MRT railroad defect inspection system. The inspected defects are clustered by the inspection zone they are in. Inspection zones include: 1. rail head, 2. rail foot, 3. fastening, 4. tie, and 5. ballast (for ground railroad) or floor (for elevated or underground railroad). In other words, we must divide the input information into five non-overlapped zones to inspect.

# Chapter 2 Data Pre-Processing

## 2.1 Hardware Configuration

Our hardware configuration is shown in Figure 3.1. This configuration is applied to both sides of railroad to cover complete railroad inspection range. The light source is Toa Lighting HJW-1000 search light. The sensor is e2v AViiVA UM4 CL 8K line-scan camera link line scan linear charge-coupled device camera. The camera link acquisition is Euresys Grablink Expert 2. By this configuration, we can obtain one-side railroad image information and store them as a file into server. Hence, after one inspection procedure, we will obtain two files containing both sides of railroad image information.

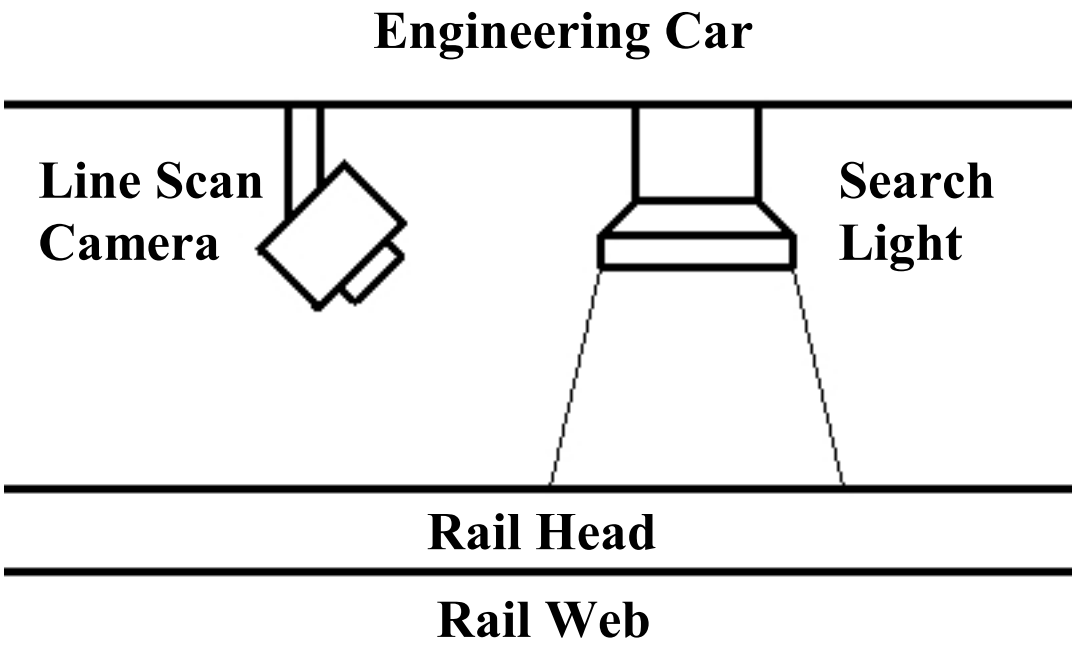



Figure 2.1 Hardware configuration on one side of rail.

## 2.2 Method for Loading File

For a complete inspection, engineering train could travel for 10 or more kilometers, thus the file could be very titanic. For width of 816 pixels at 1.971mm/pixel, 10-kilometer image information will be about 3.856GB file size. This fact shows that it is nearly impossible to load the whole file into memory at one time, so we need to load the file page by page and integrate defect information after individual page inspection. Out typical page height is 800 pixels, which is adequate for rail head bound detection. Each page can be considered as an image. Our system inspects each page to find defects using the following inspection processes. Figure 2.2 is a sample page.

However, page inspection has a problem that some fastenings could be cut into different pages, so that these fastenings are impossible to detect across boundary. Thus, the next page should keep a part of rows from the current page to avoid fastening misdetection. The number of rows to keep is estimated by fastening detection process. Moreover, we will not inspect the whole page to prevent repeated inspection of the kept part.

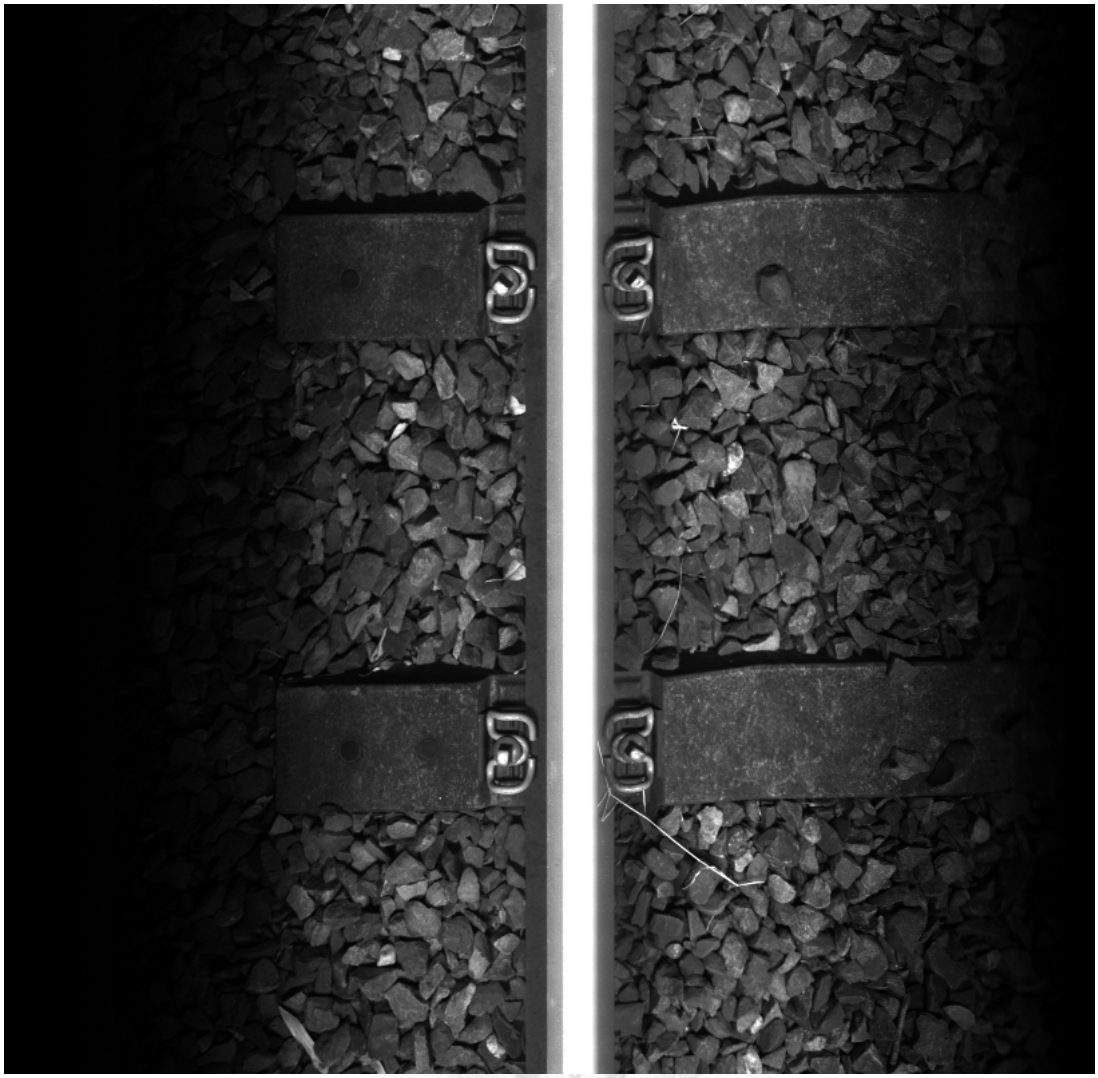
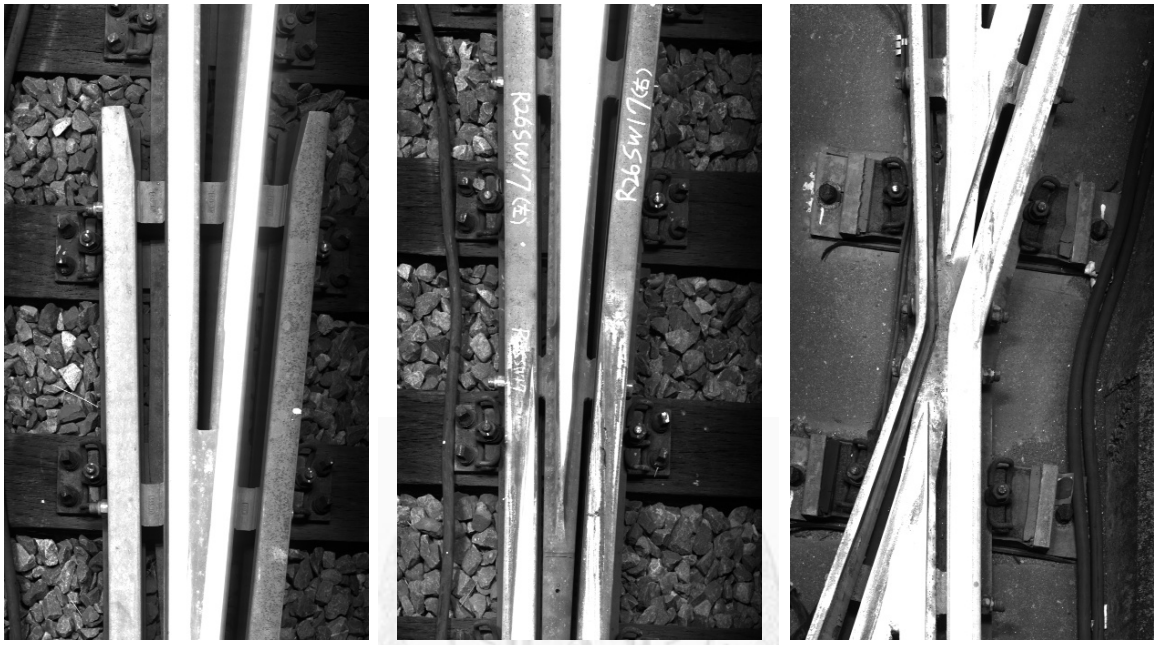


Figure 2.2 Captured image page (1:2 size).

# Chapter 3 Inspection Method

## 3.1 Railroad Switch Detection



(a) (b) (c)

Figure 3.1 Track switches.

Railroad switch detection is the first step for our inspection cycle. If a page has railroad switch, like Figure 3.1, we will apply special inspection procedure, otherwise apply normal procedure. First, we determine a detection region, and then determine a threshold value for binary thresholding to emphasize rail-like objects. Moreover, classify these objects into three classes: large, medium, and small by two area threshold values. We care about large and medium objects only. If any object is large then we determine as a switch object. Otherwise, we analyze all medium objects. Because ideal rail must connect from previous page to next page, rail objects appear in this page should touch upper edge and lower edge. Moreover, rail should be long and thin. However, due to some noise issues, these objects could be near edge but do not touch edge. Hence, we

filter out all medium objects which are near edge and the aspect ratio is larger than user-defined aspect-ratio limit. After filtering out these objects, we accumulate the width of each object. If this accumulated value is wider than the ideal rail width, we determine this page to have track switch and vice versa.

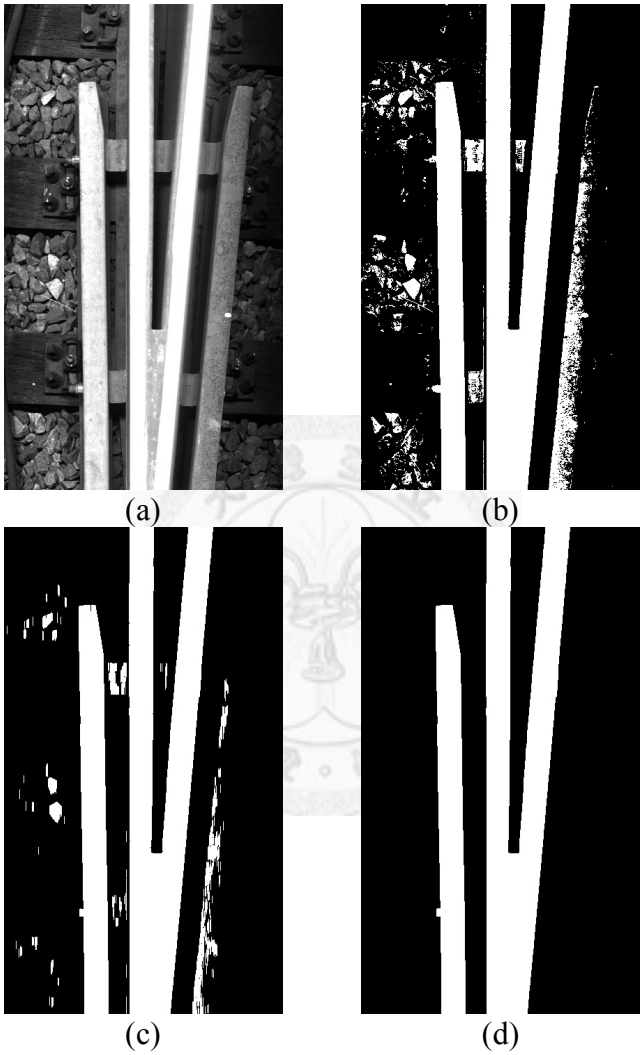



Figure 3.2 Intermediate results of filtering medium objects. (a) The switch image. (b) The result image after grayscale binary thresholding with 127. (c) The result image after 11x1-kernel opening. (d) The result image after area thresholding with 40,000 pixels and 4,000 pixels. Obviously, there are two medium objects in the result (d).

## 3.2 Rail Head Bound Detection

Rail head bound detection plays an important role in defect inspection because it relates to defect detection rate in rail-head zone and rail-foot zone. Good detection result can help to divide inspection zone correctly. Rail head bound detection is an edge detection issue essentially because rail head is obviously brighter than rail foot. However, because defects usually appear on the bounds of rail head, detecting definite locations of both bounds are not simple. The following is our rail head bound detection method. First, we determine a detection range, and then apply histogram equalization to enhance intensity contrast. After that, we need to determine a threshold value for binary thresholding which should emphasize rail head. Rail head has an unstable intensity appearance because defects and unstable location because of driving pathway, so we could not determine an adequate threshold value easily. However, the width of rail head is very stable, observing from image information. Thus we can limit the width of rail head to obtain a more accurate location of both bounds. Hence, we determine the threshold value dynamically. We try grayscale value from 254, decreasingly, for binary thresholding. After each binary thresholding, we apply morphological filtering to link near objects or smooth their contours. This procedure repeats until we obtain an object which is nearest to the ideal rail head width. After obtaining this object, we detect its leftmost edge and rightmost edge as rail head bounds.

## 3.3 Fastening Detection

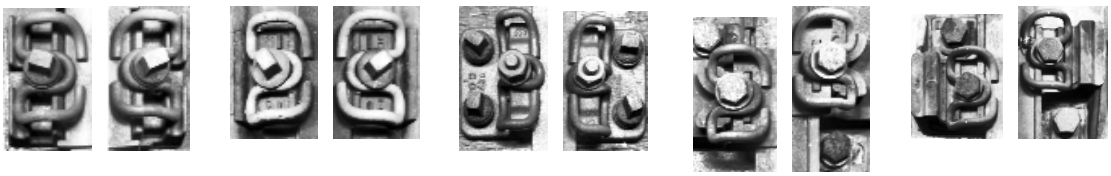
Fastening detection is an essential part of inspection procedure. Any fastening defect may lead to a catastrophe. For a good defect inspection rate, a great fastening detection rate is necessary. However, many kinds of fastening exist with very different shapes and looks. Moreover, fastenings of the same kind have unstable grayscale appearance due to rusting or oil. Hence, we make golden template for each kind of fastenings and apply template matching to detect them. Our template matching algorithm is Normalized Cross-Correlation (NCC). This algorithm has good noise tolerance and good stability on matching evaluation. After NCC computation for each kind of fastenings, we will obtain distributions of matching evaluation as many as the number of kinds of fastenings we want to detect. We can integrate these distributions into one distribution by keeping maximum values on each position. After that, we determine a threshold value to keep evaluation values which are high enough to be considered as matched. We then find local maximum values. Each of them should be far enough as the distance between two corresponding types of fastenings. This ideal distance information is calculated when we produce golden templates. The location of these maximum values is preliminary result of fastening detection.

After preliminary detection, it is still possible that some fastenings are undetected due to serious defects on them so that the evaluation values are poor. Hence, we design a remedy mechanism. Because general kinds of fastenings are paired, we can use this fact to remedy unpaired fastenings. When producing golden templates, we can calculate relative position to rail head bounds for each kind of fastenings. By this relative position information, we can recover the position of the mate of each unpaired fastening to ensure every fastening is paired. After remedy, we can obtain the information of fastenings

including kind, position, and size.

(a) Left-Side (b) Right-Side

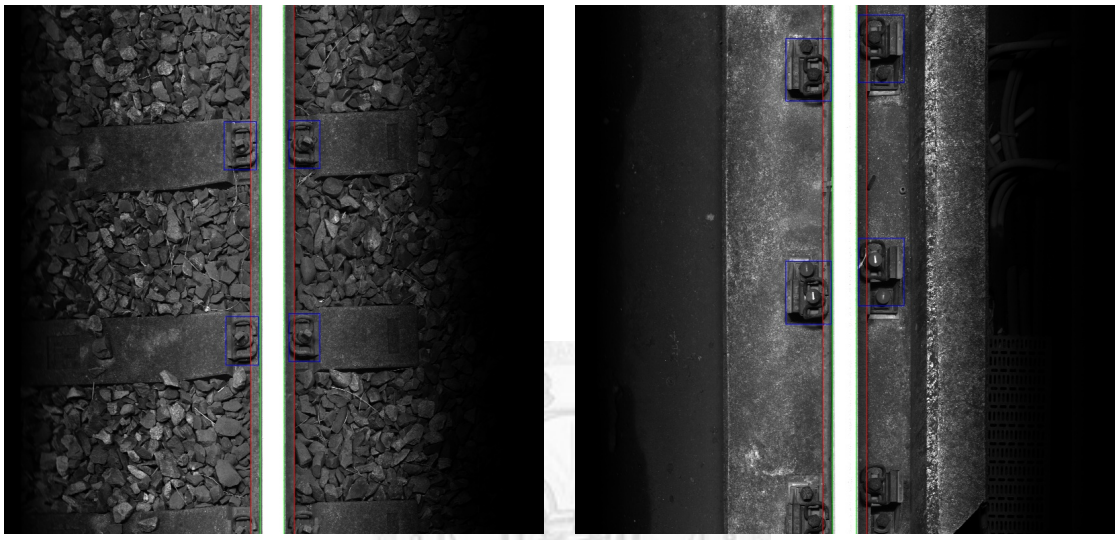
Figure 3.3 NCC result images. From left to right: the template, the interested image, and the NCC image.



(a) (b) (c) (d) (e)

Figure 3.4 Different pairs of user-generated fastening templates

After rail head bound detection and fastening detection, we obtain the normal location information. According to the locations of rail head bounds and fastenings, we can determine the locations of rail foot bounds and railroad ties by referring to user-defined relative location parameters. We can follow this complete location information to inspect individual zones.



(a) (b)

Figure 3.5 Schematic images with rail head bounds (green), rail foot bounds (red), and fastenings (blue) emphasized.

# 3.4General Defect Inspection

For most inspection zones, a general defect inspection method is applied. First, we determine two groups of values. One is the constant group and the other one is the mean-offset group. Each group has two user-defined values. One is for bright defect inspection, one for dark. The values in constant group, $C_b$ and $C_d$, can be used directly as threshold values. The values in mean-offset group, $m_b$ and $m_d$, are not used directly but are calculated for two mean-dependent threshold values. The "mean" is the average grayscale value of interested inspection zone. The real larger threshold value, $M_b$, is calculated by the mean added with the value for bright defect inspection and the real

smaller threshold value, $M_d$, is calculated by the mean subtracted with the value for dark defect inspection. Any object with larger grayscale value than $C_b$ or $M_b$ is a possible bright defects and with smaller grayscale value than $C_d$ or $M_d$ is a possible dark defect. Obviously, we can simplify these four values into two threshold values $T_b$ and $T_d$ that can be used directly by the following logic: $T_b = min(C_b, M_b)$ and $T_d = max(C_d, M_d)$.

We can obtain a bright-defect image by binary thresholding with $T_b$ and a dark-defect image by inverse binary thresholding with $T_d$. Moreover, we can apply any region search algorithm to obtain region information of each defect. Position, size, orientation, and average grayscale of any defect are necessary information that we record into server. Furthermore, we can assign some filtering parameters, e.g. area limit or aspect limit, to filter these defects. This filtering process is very helpful to reduce noise objects and simplify defect report.

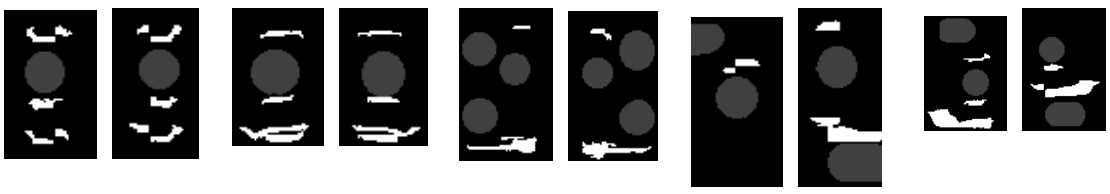
Most zones use the above inspection procedure but two do not. Methods used in these special zones are described later.

## 3.5 Rail Head Inspection

Rail head inspection is one of two inspection zones where we do not apply the general defect inspection described above. Rail head inspection is the most important part of inspection procedure because any defect on rail head may lead to a catastrophe. We need to enhance our general inspection method to be more sensitive to abnormality on rail head. Because texture of rail head has vertical orientation, we calculate vertical line profile of rail head, and record mean grayscale value and variance of each line profile. After that, we determine a constant coefficient $C$. Objects with smaller grayscale value than the mean subtracted by the variance multiplied by $C$ are considered as defects. Similar to general defect inspection, we can filter these defects as we wish.

## 3.6 Fastening Inspection

Fastening inspection is another inspection zone not to apply the general defect inspection method. When inspecting fastenings, we focus on three kinds of serious defects: broken, loose, or missing fastenings. Thus, we design the masks for each kind of fastenings. Our idea is to inspect upper retaining ring, lower retaining ring, and screw bolt individually. For the retaining ring inspection case, it is difficult to inspect the body of ring due to great grayscale variation. However, shadow always exists if retaining ring is normal. Shadow is the most stable feature of ring. If we select the grayscale feature of the body of retaining ring as inspection part, it is unstable and may easily lead to false positives or misdetection. Hence, we artificially draw the region of retaining ring and map into mask as white part, for upper ring inspection, and light gray part, for lower ring inspection. Screw bolt is another critical inspection part. If screw bolt is loose or missing, it is a serious defect even though retaining ring is not crooked. Hence, similarly, we artificially draw the region of the screw bolt of fastening and map into mask as dark gray part. The remaining black part corresponds to the region we do not inspect. When inspecting a fastening, we use its corresponding mask to obtain the regions we are interested in. We apply the general defect inspection on upper retaining ring part and lower retaining ring part. Moreover, apply a single limit value for screw bolt inspection. If the mean grayscale of the screw bolt part is lower than the limit value, we determine it as a defect.



(a) (b) (c) (d) (e)

Figure 3.6 Different pairs of user-generated masks for fastening templates shown in Figure 3.3.

## 3.7 Flowchart

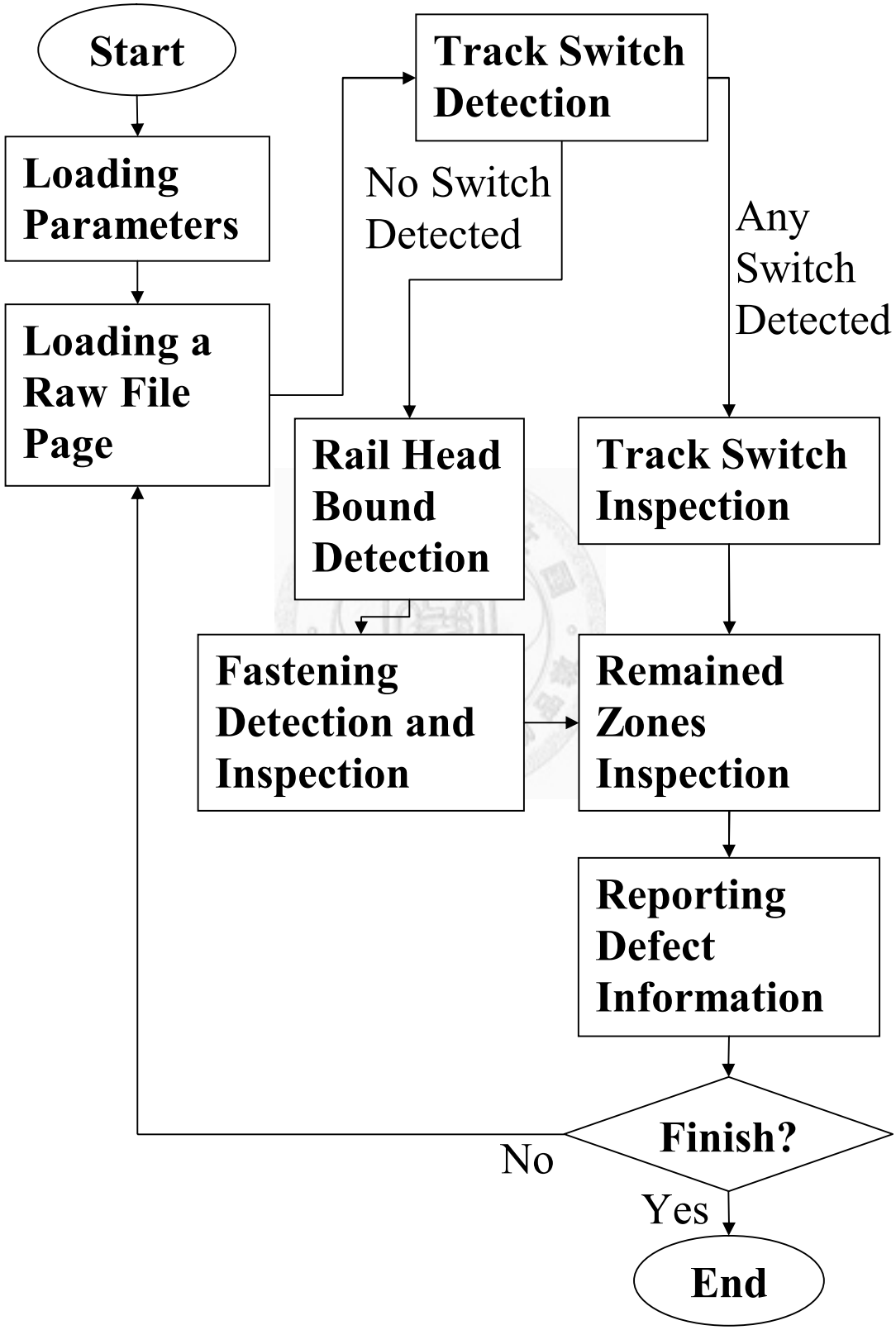



Figure 3.7 Inspection system flowchart.

# Chapter 4 Experimental Results

We test our inspection system at three MRT sections twice: both up and down directions. These sections have their own characteristics. The first is the ground section from Fuxinggang to Zhongyyi. The second is the elevated section from Jiantan to Shilin. The third is the underground section from Zhongshan to Minquan West Road. The target artificial defects are placed in each section with arbitrary numbers in each inspection zone. The result statistics, shown in the following, depend on the inspection rate of these artificial defects.

Overall, the inspection rate is around 80%. The result in the elevated section has a slightly lower inspection rate than the other two due to rain. Many rain drops appear on the railroad and hinder inspection. Due to the variation of weather condition, an adequate adjustment of inspection parameters is necessary. Hence, we need a different group of parameters for rainy weather to obtain an acceptable inspection performance. Thus, due to the weather issue, we must prepare at least two groups of parameters for normal and rainy weather conditions.

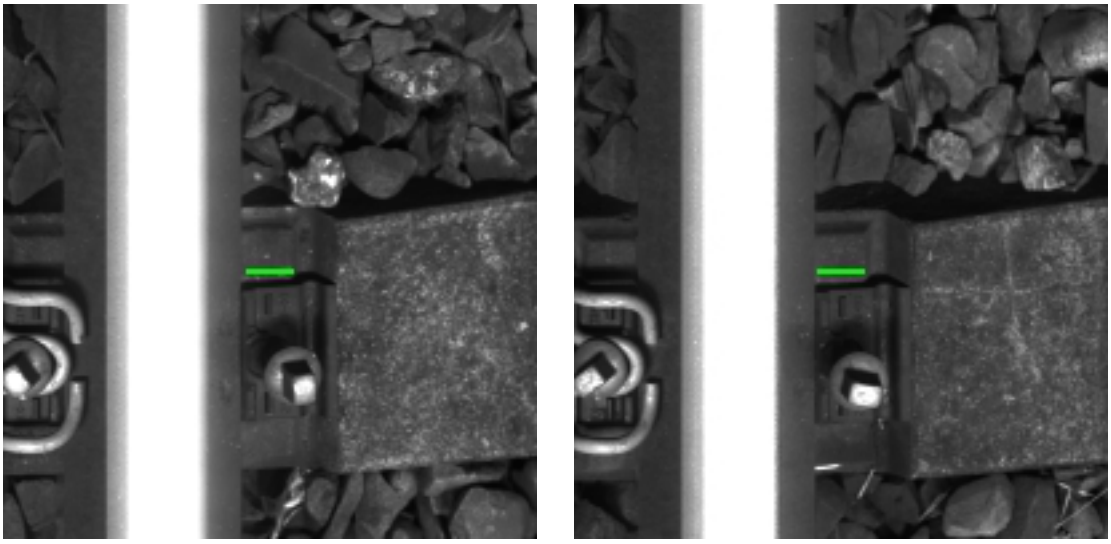
Figure 4.1 The sample page of the ground section.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 37 | 30 | 81.08% |
| Right Rail | 31 | 31 | 100.00% |
| Total | 68 | 61 | 89.71% |

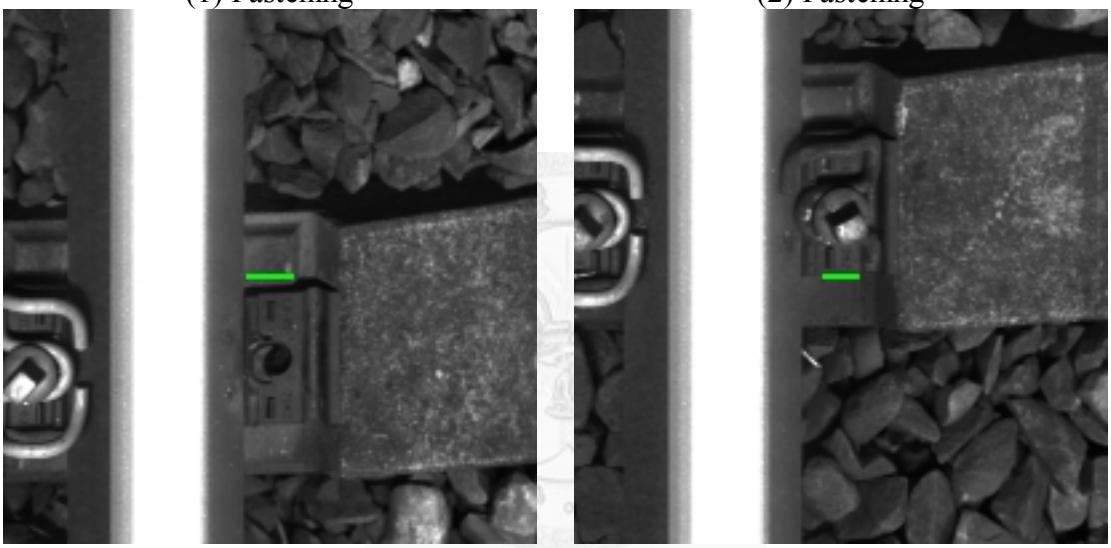
Figure 4.2 The inspection statistics for the ground section up direction.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 49 | 39 | 79.59% |
| Right Rail | 50 | 40 | 80.00% |
| Total | 99 | 79 | 79.80% |

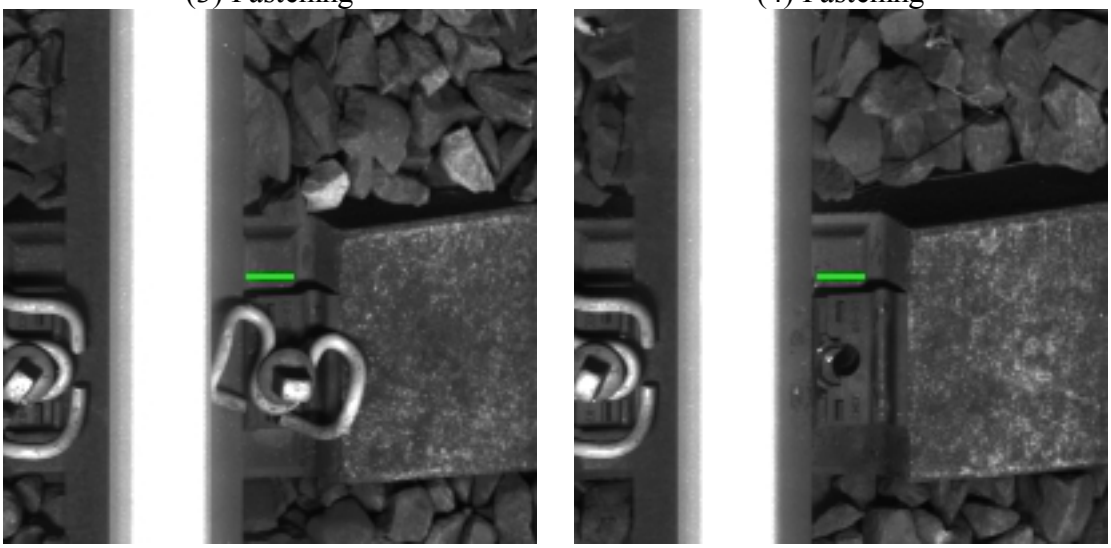
Figure 4.3 The inspection statistics for the ground section down direction.



(1) Fastening (2) Fastening

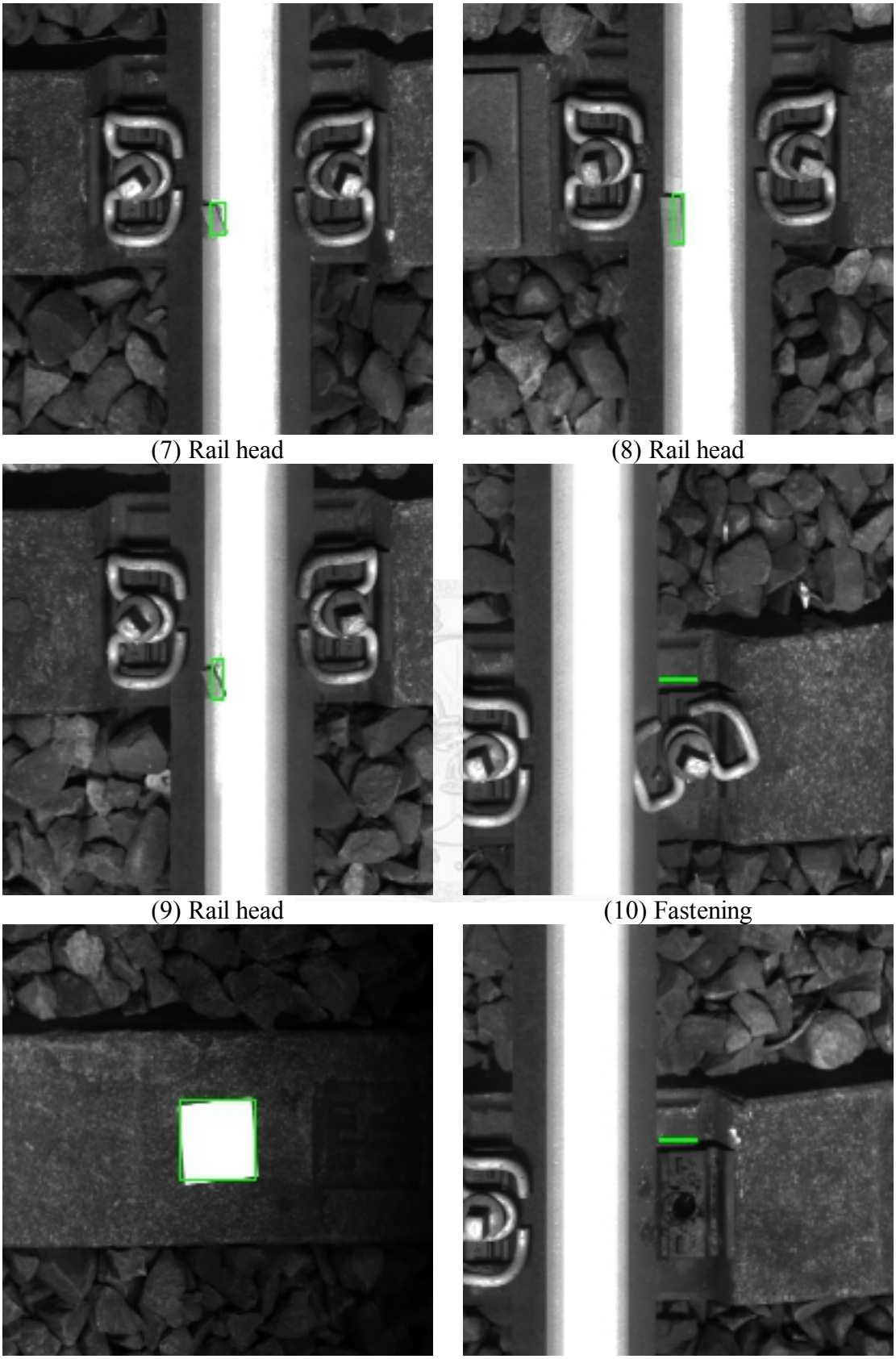


(3) Fastening (4) Fastening



(5) Fastening (6) Fastening

Figure 4.4 Inspected defects in the ground section. Up direction left rail (I).

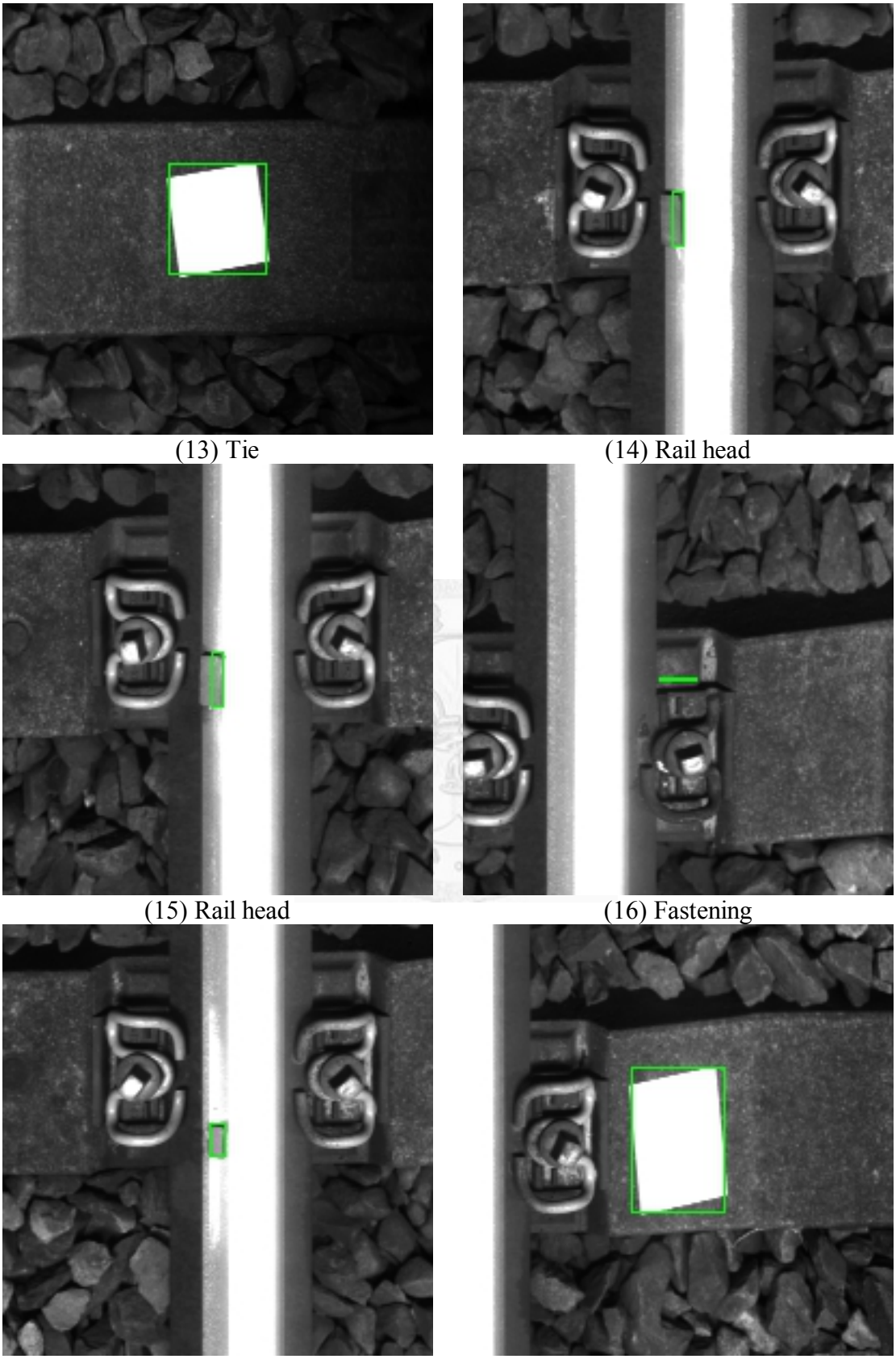


(7) Rail head (8) Rail head

(9) Rail head (10) Fastening

(11) Tie (12) Fastening

Figure 4.5 Inspected defects in the ground section. Up direction left rail (II).

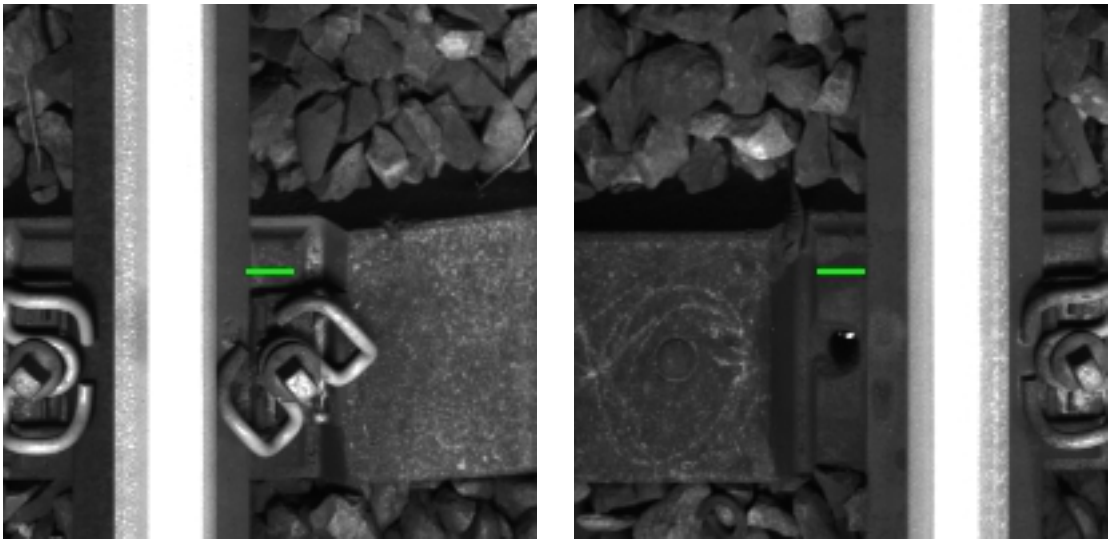


(13) Tie (14) Rail head

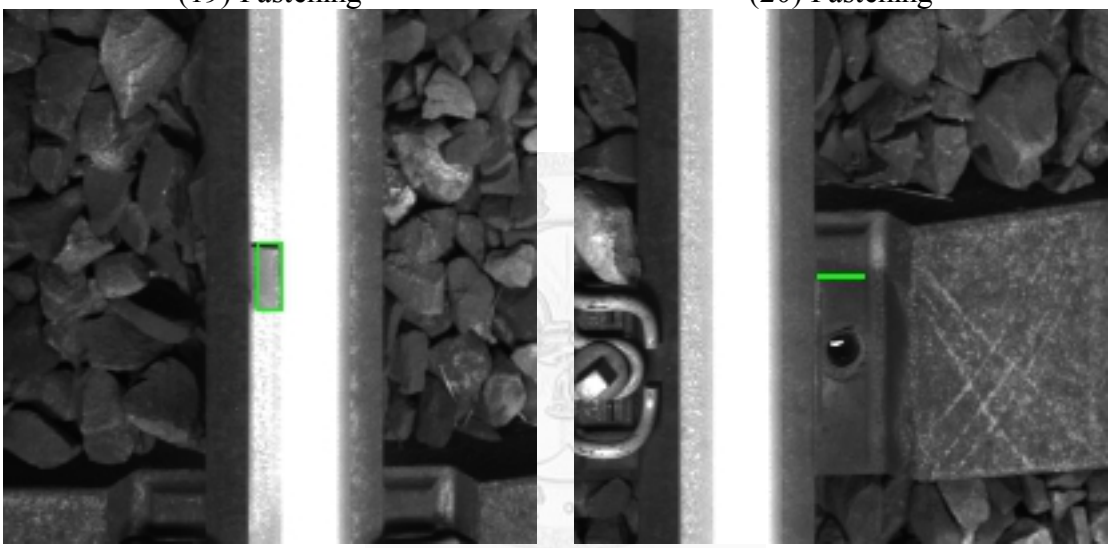
(15) Rail head (16) Fastening

(17) Rail head (18) Tie

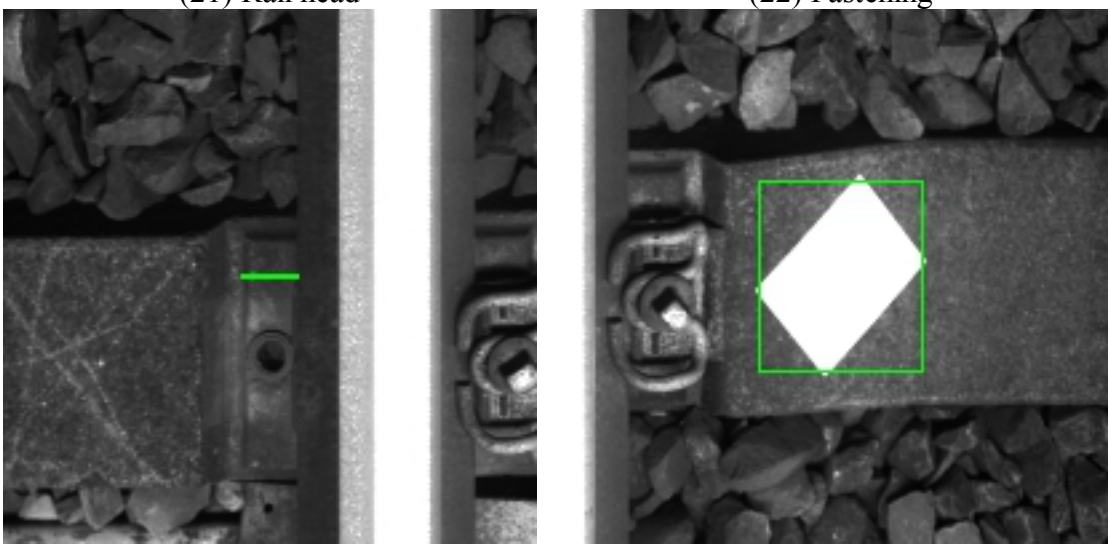
Figure 4.6 Inspected defects in the ground section. Up direction left rail (III).



(19) Fastening (20) Fastening

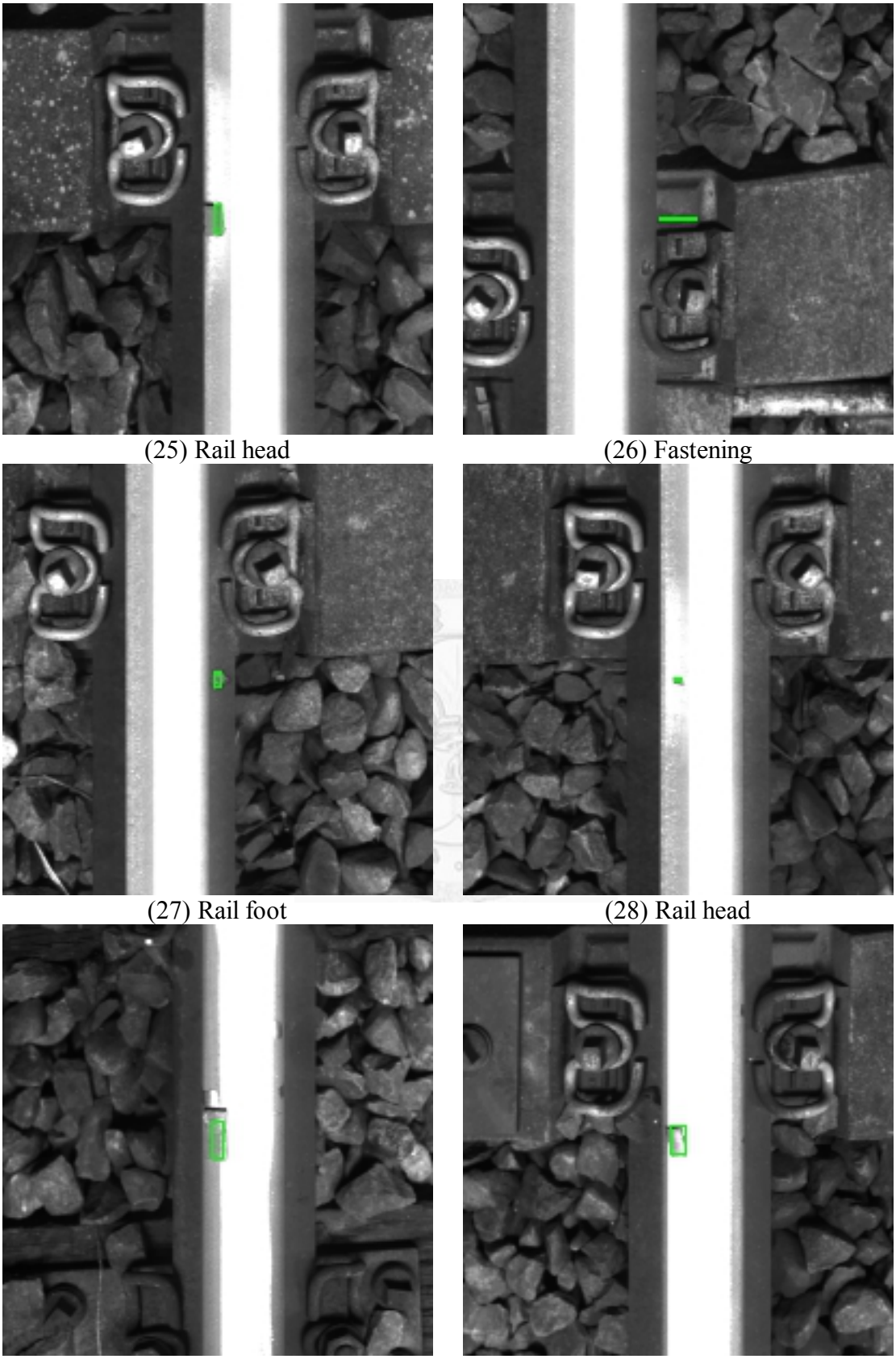


(21) Rail head (22) Fastening



(23) Fastening (24) Tie

Figure 4.7 Inspected defects in the ground section. Up direction left rail (IV).

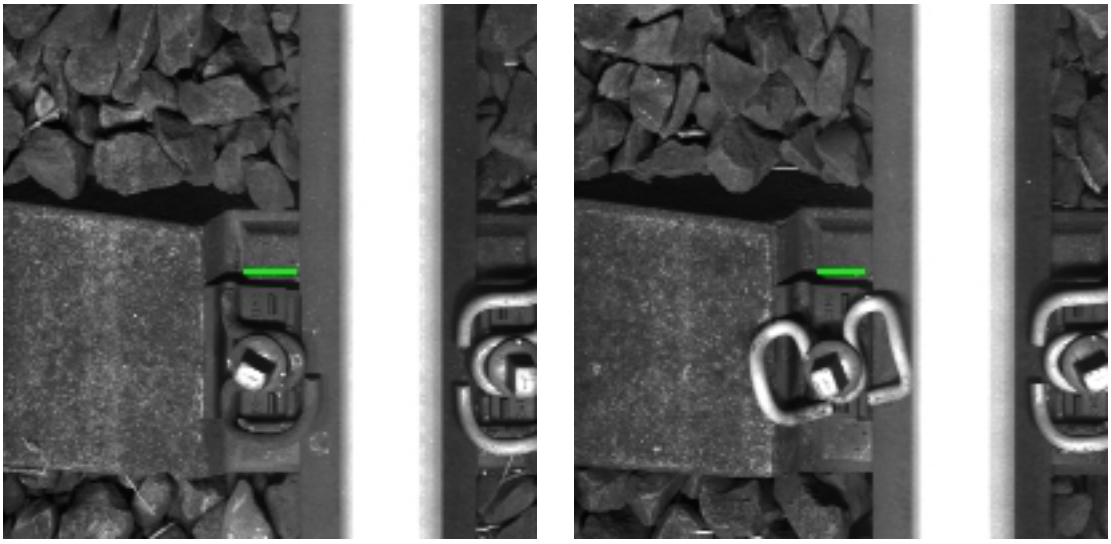


(25) Rail head (26) Fastening

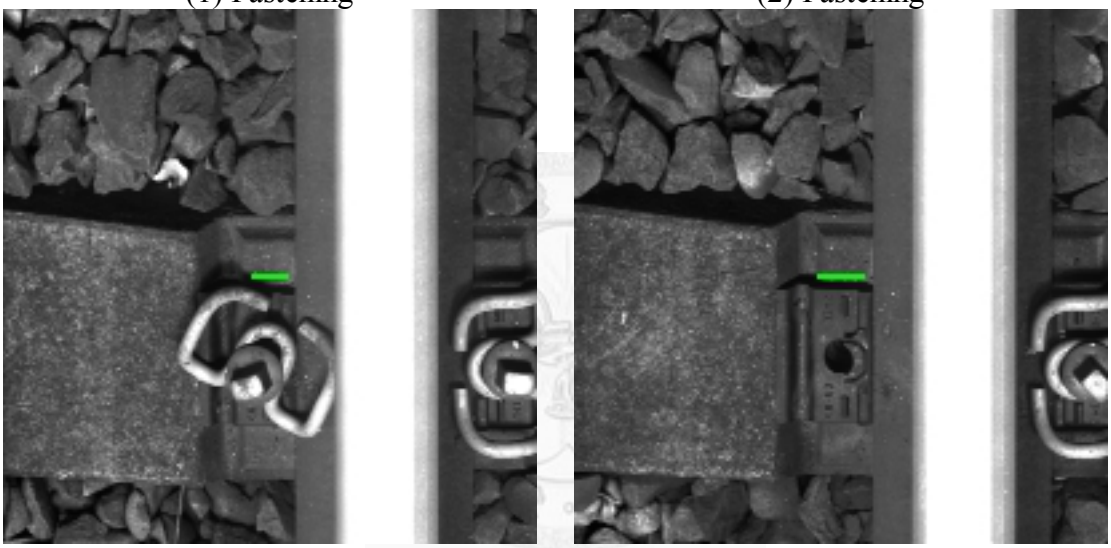
(27) Rail foot (28) Rail head

(29) Rail head (30) Rail head

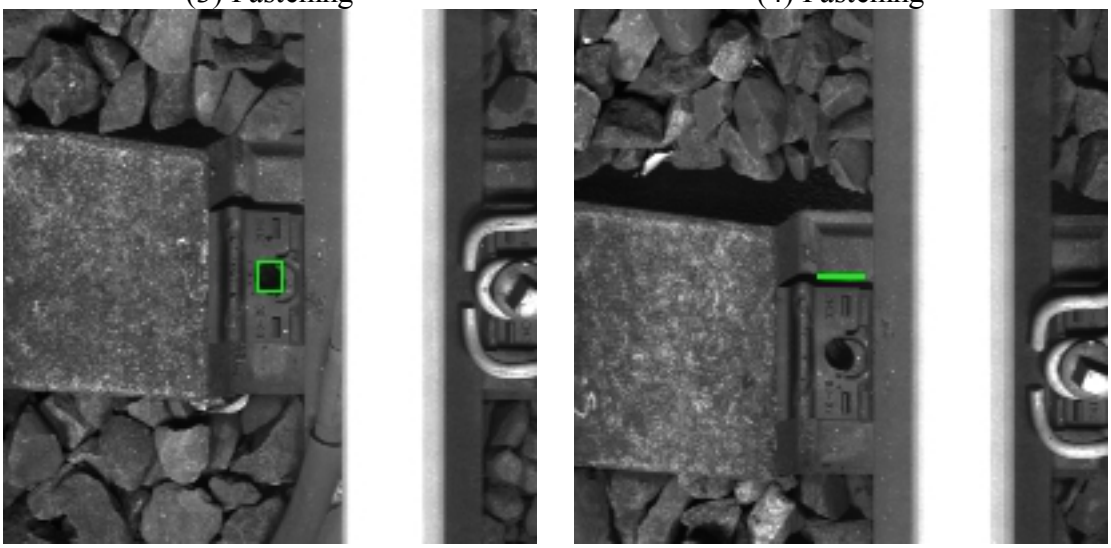
Figure 4.8 Inspected defects in the ground section. Up direction left rail (V).



(1) Fastening (2) Fastening

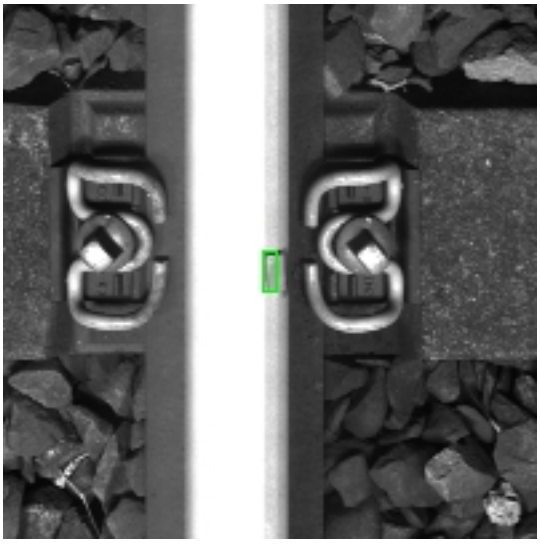


(3) Fastening (4) Fastening

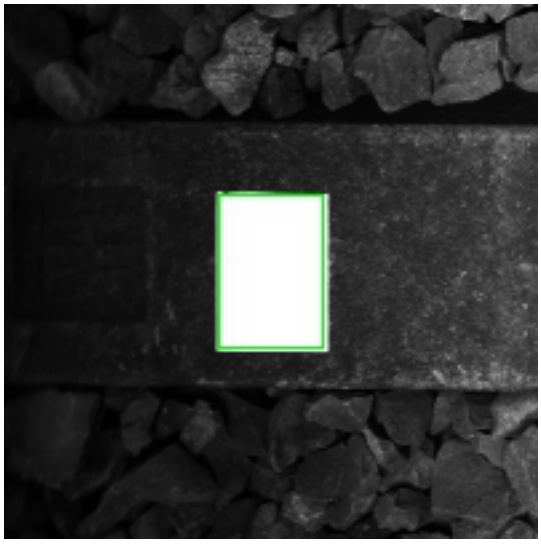


(5) Fastening (6) Fastening

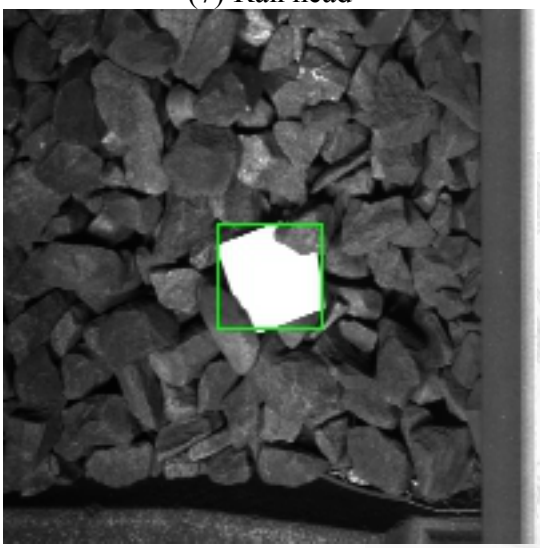
Figure 4.9 Inspected defects in the ground section. Up direction right rail (I).



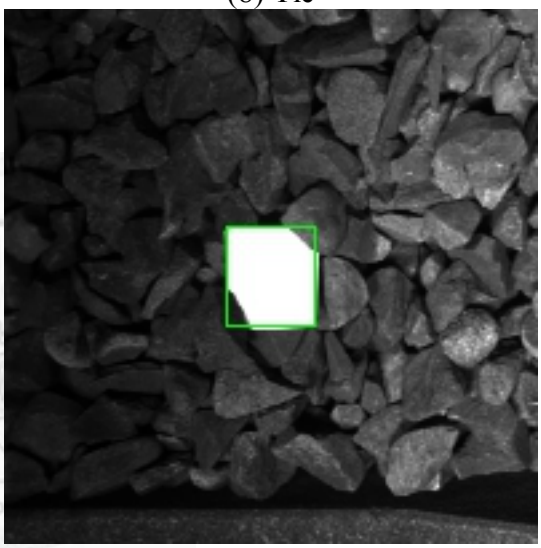
(7) Rail head



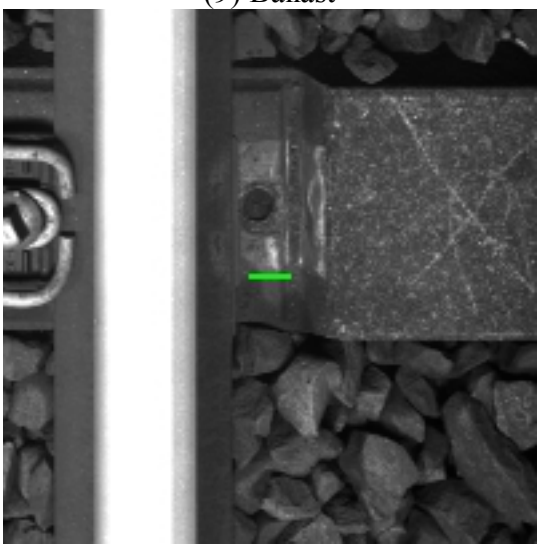
(8) Tie



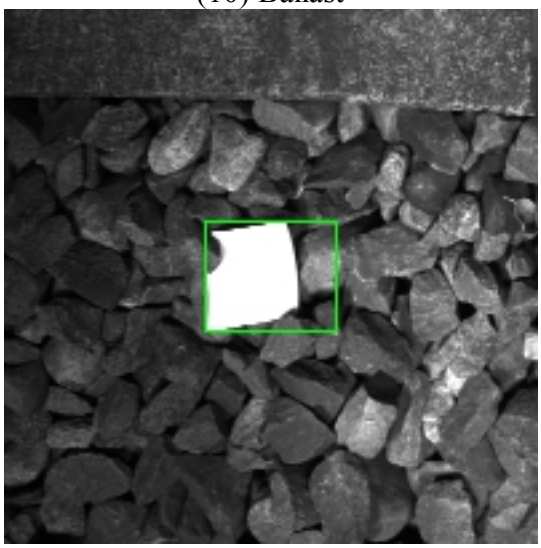
(9) Ballast



(10) Ballast

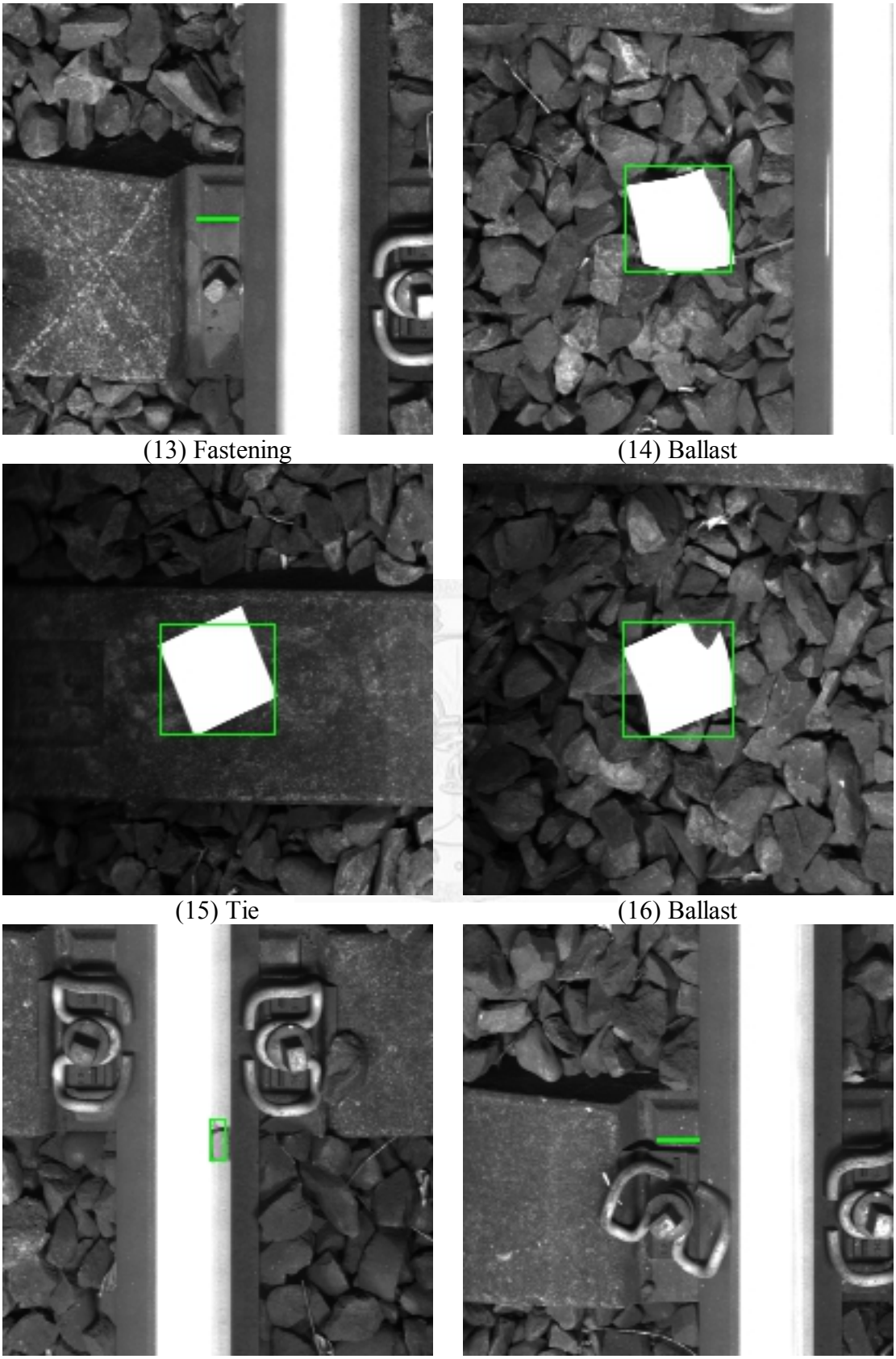


(11) Fastening



(12) Ballast

Figure 4.10 Inspected defects in the ground section. Up direction right rail (II).

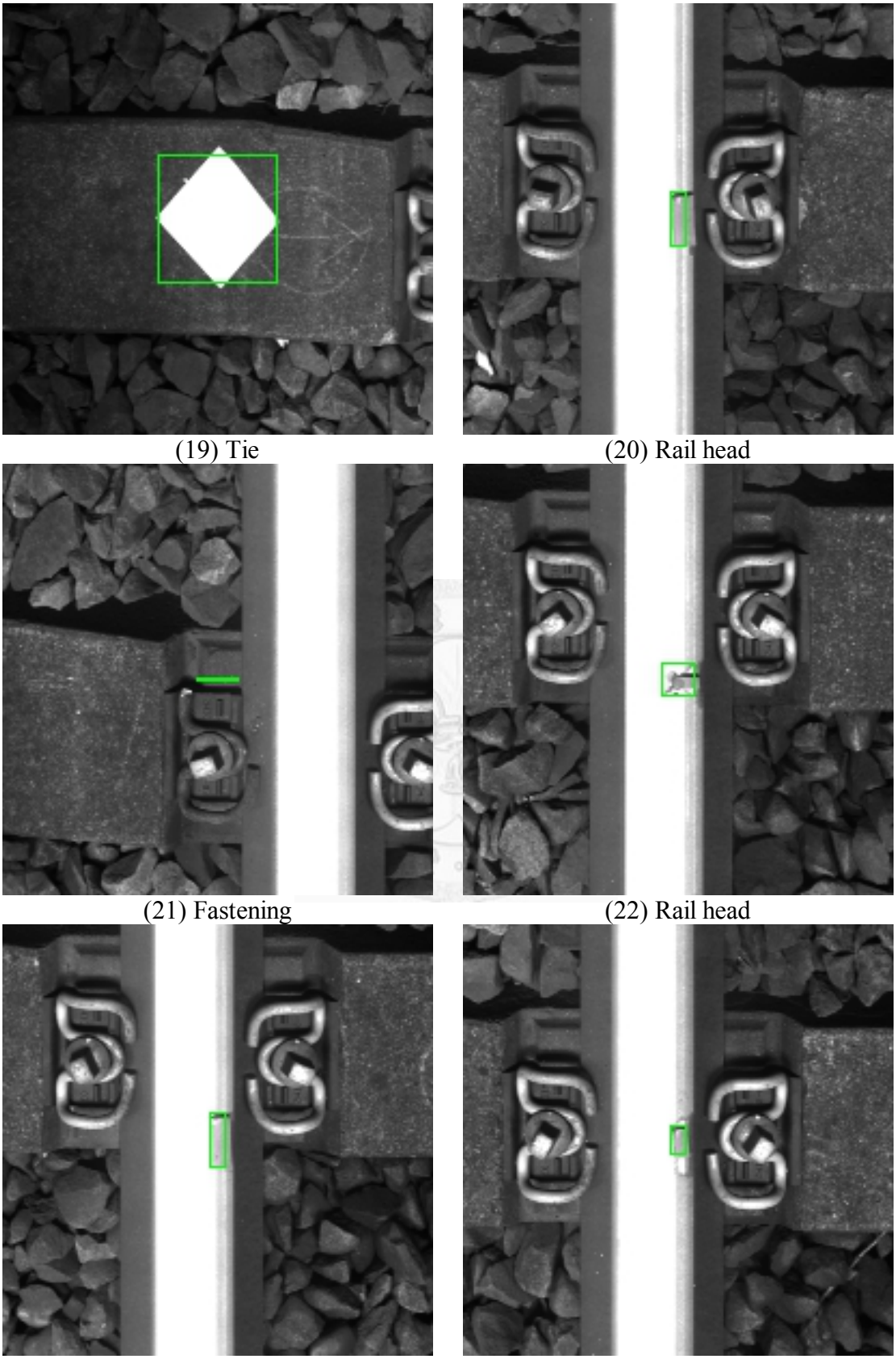


(13) Fastening (14) Ballast

(15) Tie (16) Ballast

(17) Rail head (18) Fastening

Figure 4.11 Inspected defects in the ground section. Up direction right rail (III).

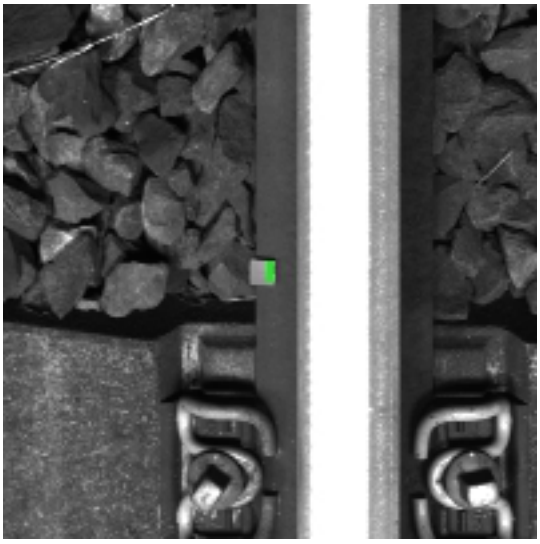


(19) Tie (20) Rail head

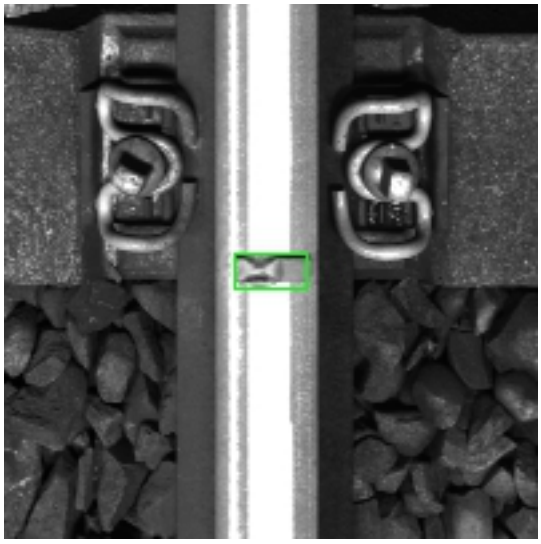
(21) Fastening (22) Rail head

(23) Rail head (24) Rail head

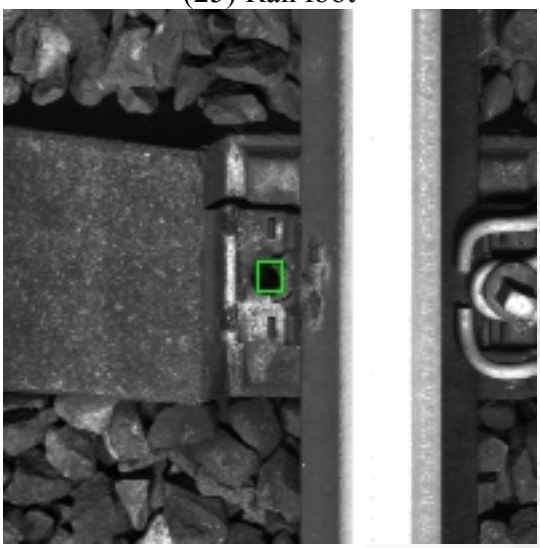
Figure 4.12 Inspected defects in the ground section. Up direction right rail (IV).



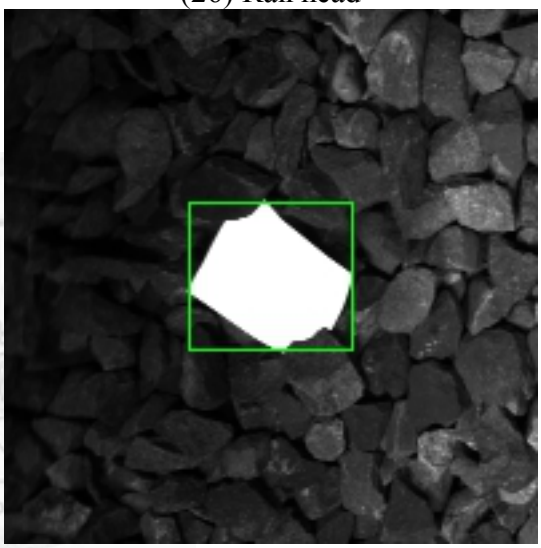
(25) Rail foot



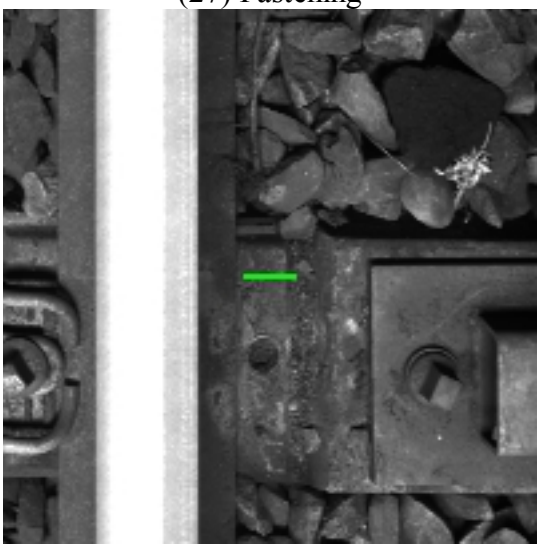
(26) Rail head



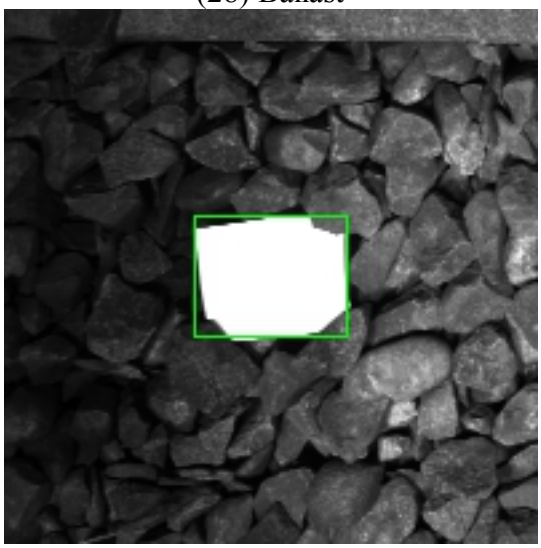
(27) Fastening



(28) Ballast

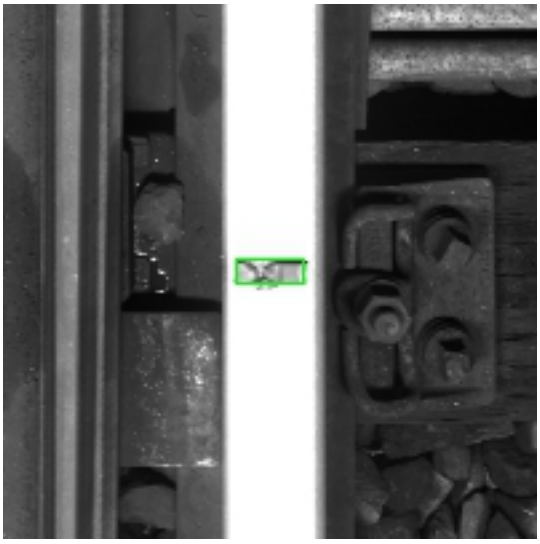


(29) Fastening



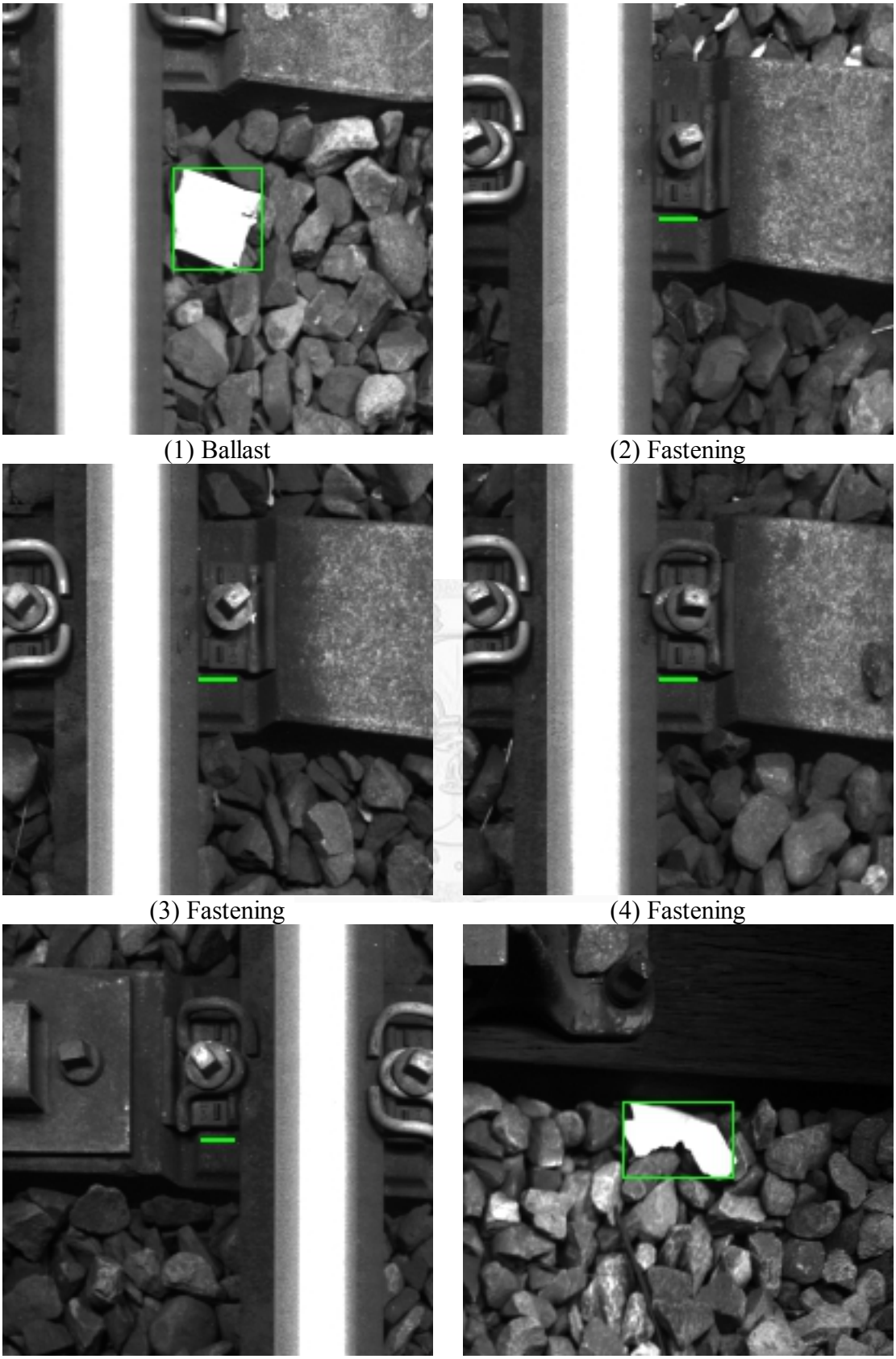
(30) Ballast

Figure 4.13 Inspected defects in the ground section. Up direction right rail (V).



(31) Rail head

Figure 4.14 Inspected defects in the ground section. Up direction right rail (VI).

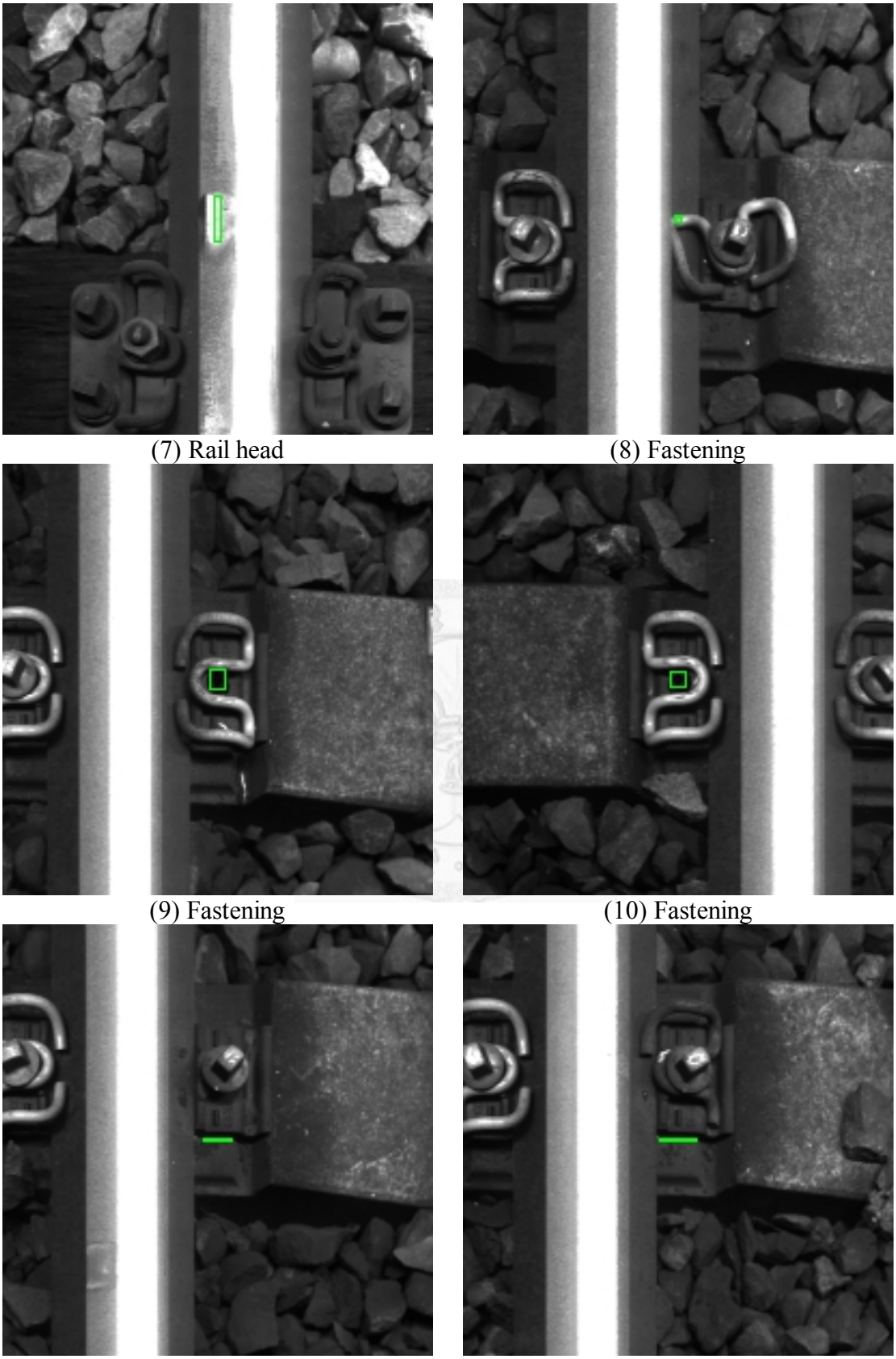


(1) Ballast (2) Fastening

(3) Fastening (4) Fastening

(5) Fastening (6) Ballast

Figure 4.15 Inspected defects in the ground section. Down direction left rail (I).

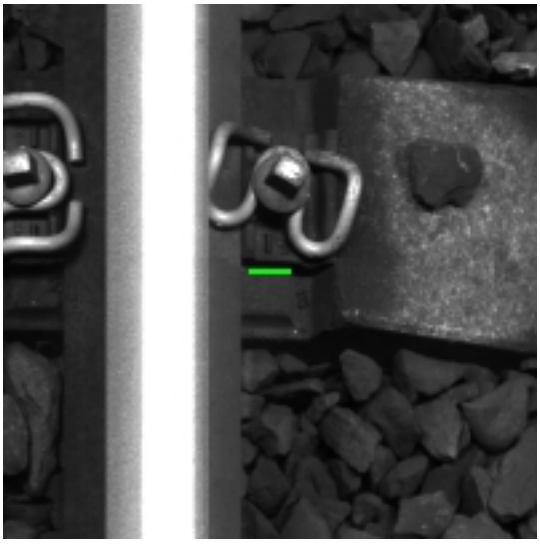


(7) Rail head (8) Fastening

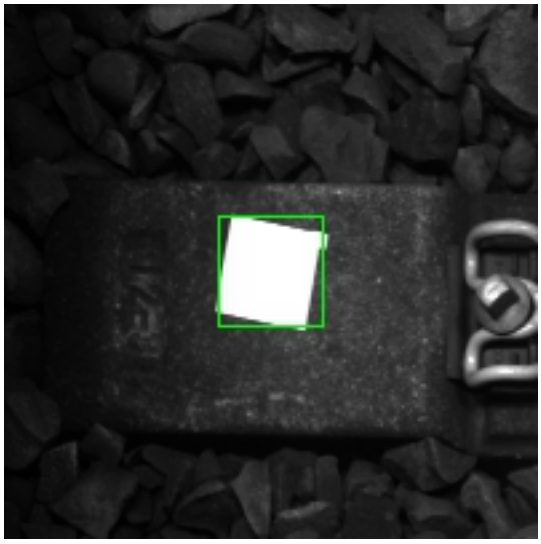
(9) Fastening (10) Fastening

(11) Fastening (12) Fastening

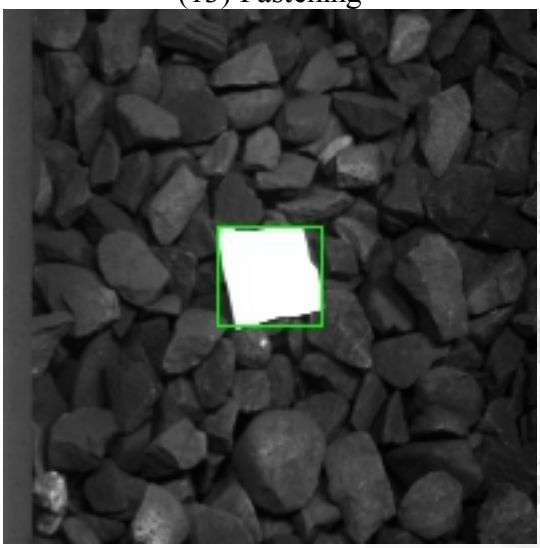
Figure 4.16 Inspected defects in the ground section. Down direction left rail (II).



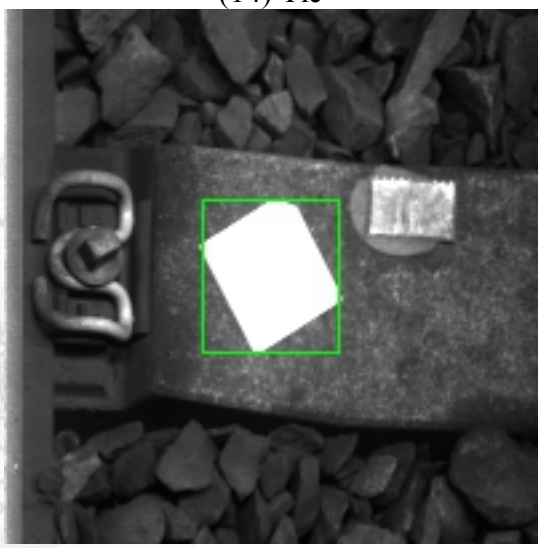
(13) Fastening



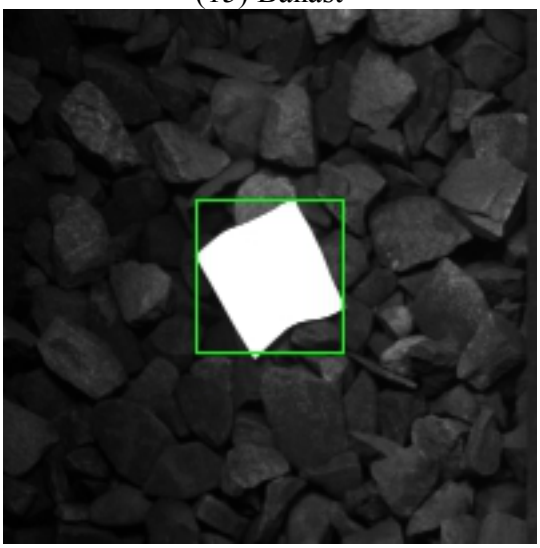
(14) Tie



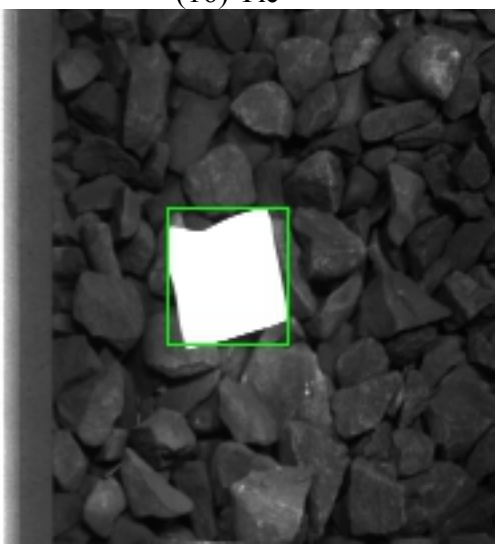
(15) Ballast



(16) Tie

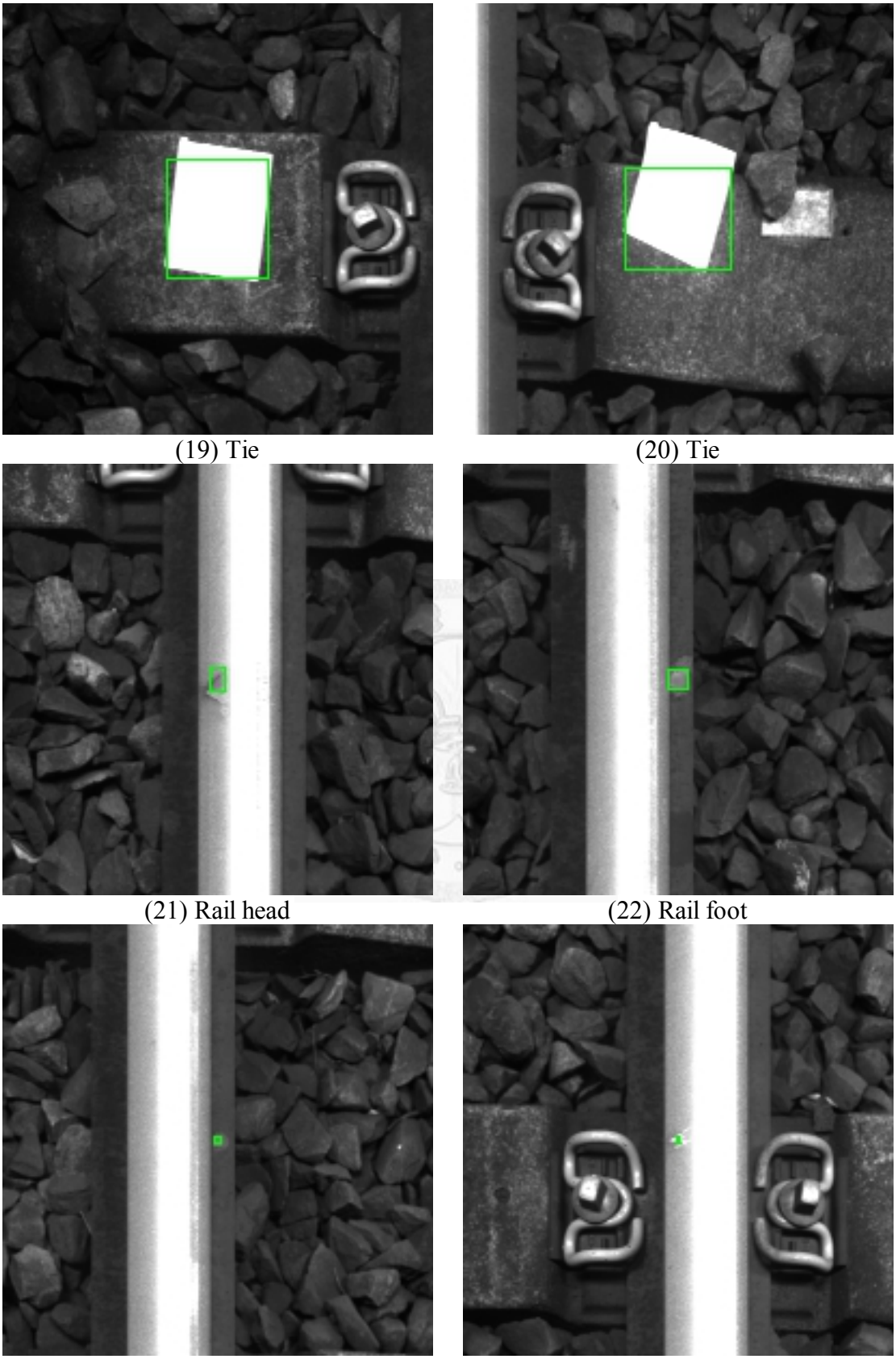


(17) Ballast



(18) Ballast

Figure 4.17 Inspected defects in the ground section. Down direction left rail (III).

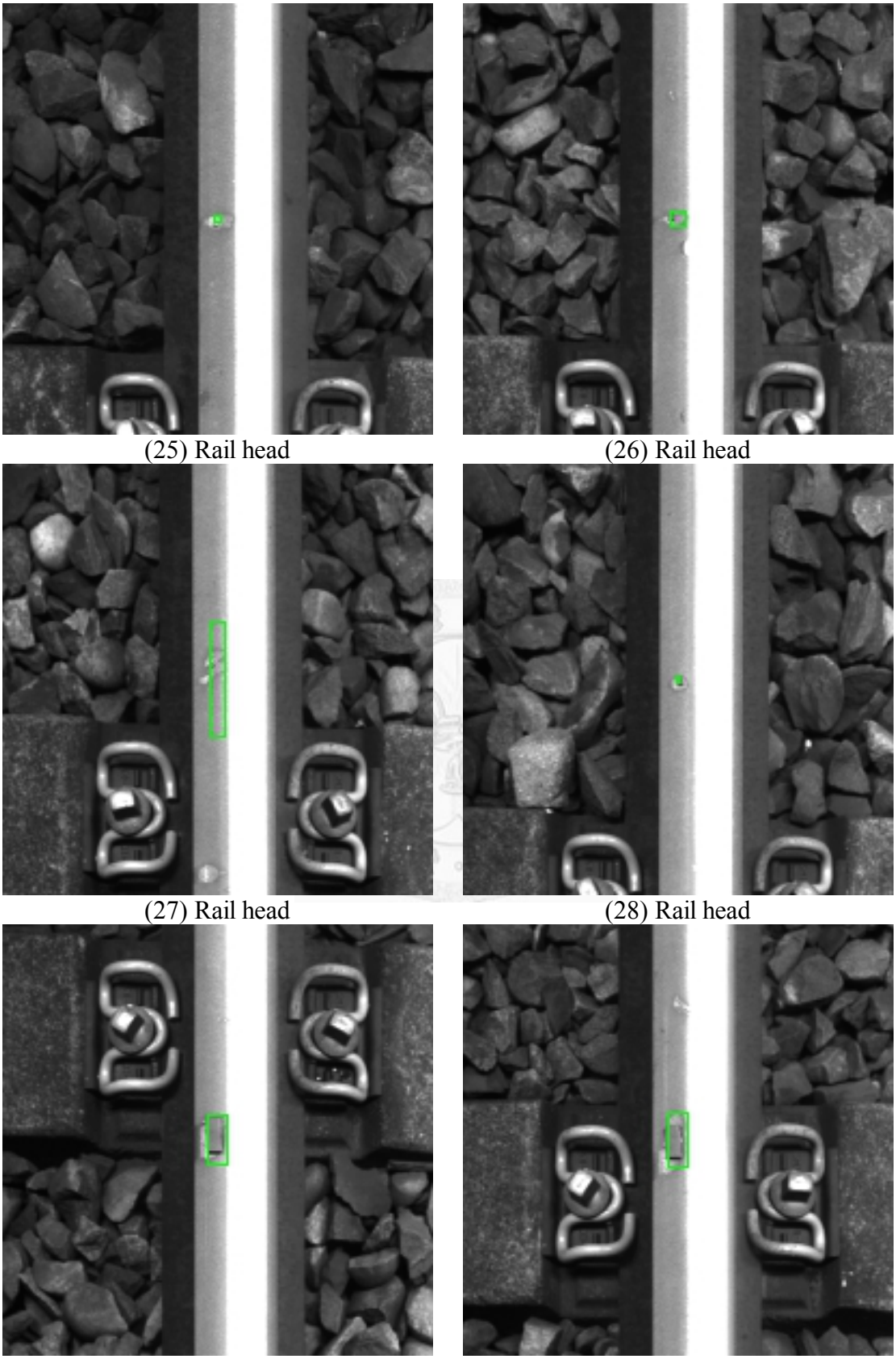


(19) Tie (20) Tie

(21) Rail head (22) Rail foot

(23) Rail foot (24) Rail head

Figure 4.18 Inspected defects in the ground section. Down direction left rail (IV).



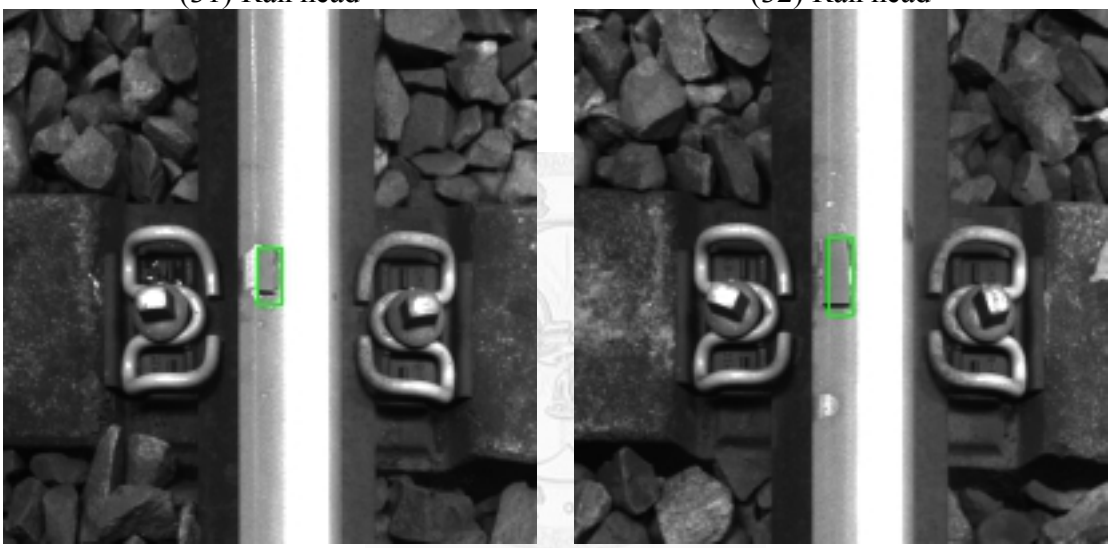
(25) Rail head (26) Rail head

(27) Rail head (28) Rail head

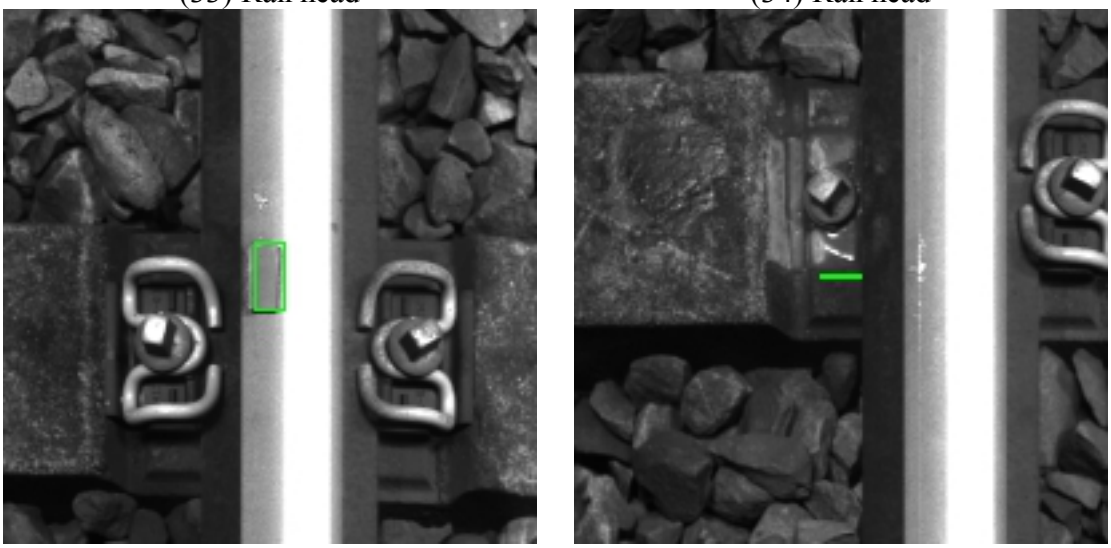
(29) Rail head (30) Rail head

Figure 4.19 Inspected defects in the ground section. Down direction left rail (V).

(31) Rail head (32) Rail head

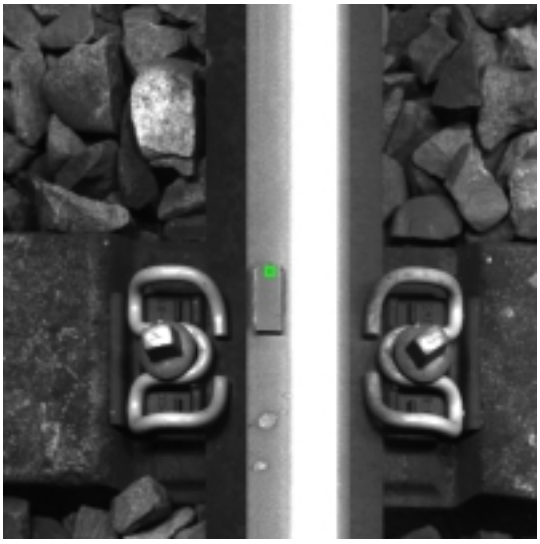


(33) Rail head (34) Rail head

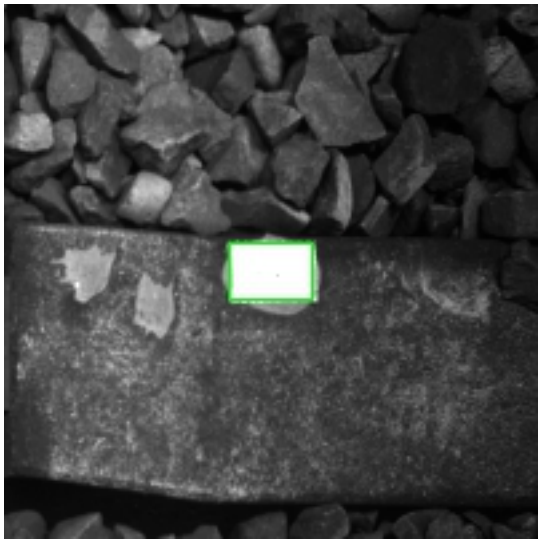


(35) Rail head (36) Fastening

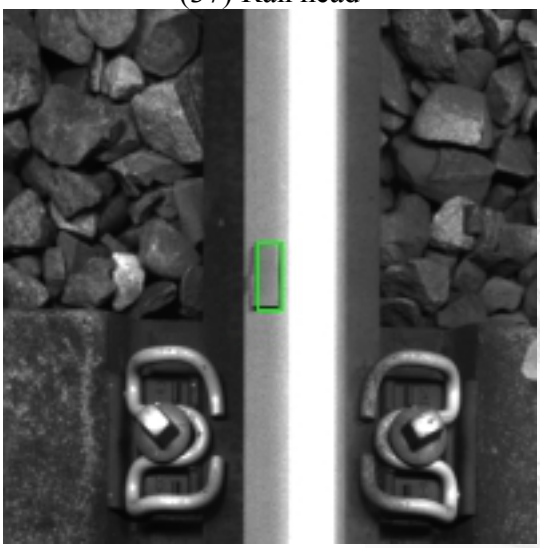
Figure 4.20 Inspected defects in the ground section. Down direction left rail (VI).



(37) Rail head

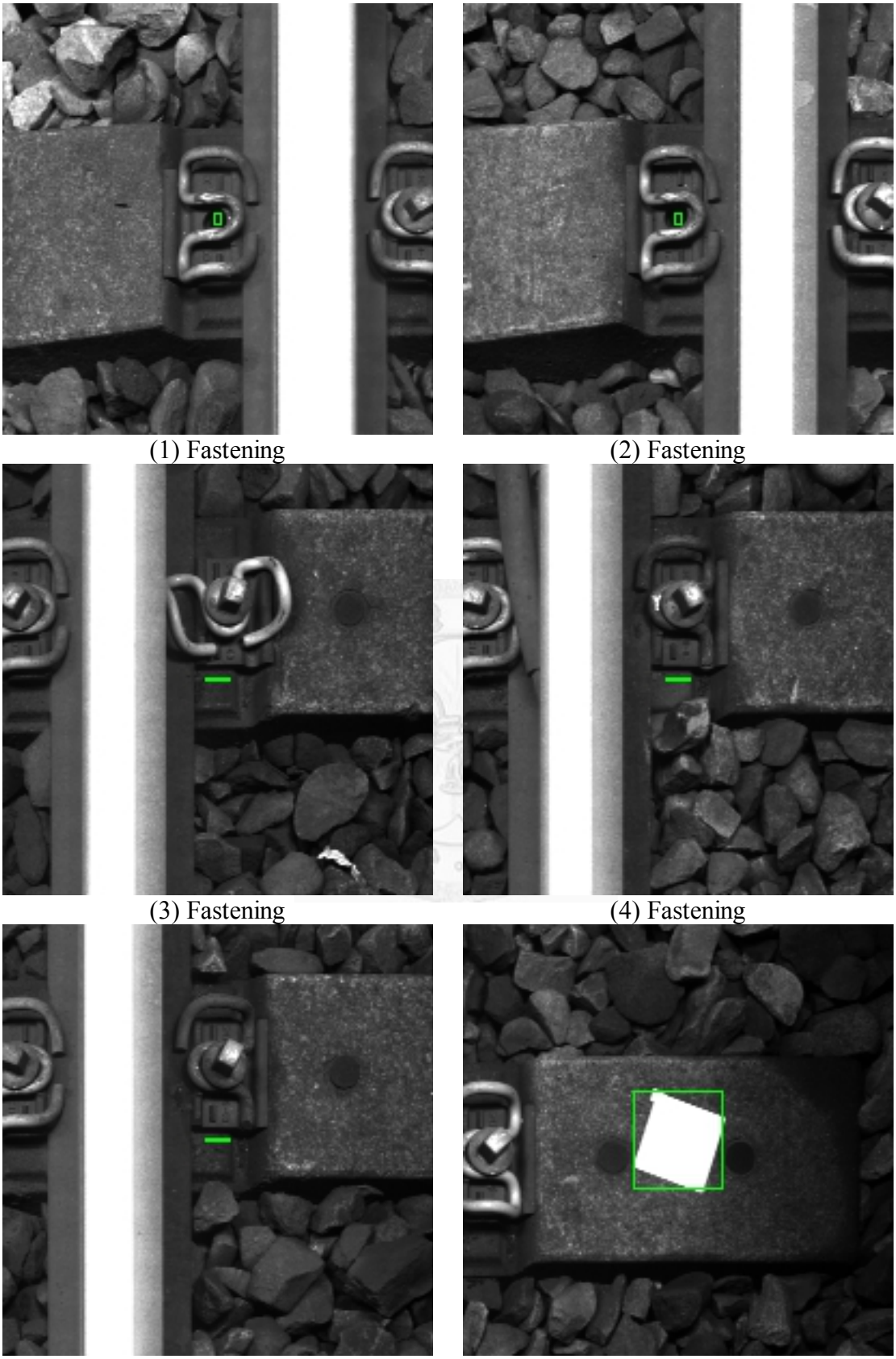


(38) Tie



(39) Rail head

Figure 4.21 Inspected defects in the ground section. Down direction left rail (VII).

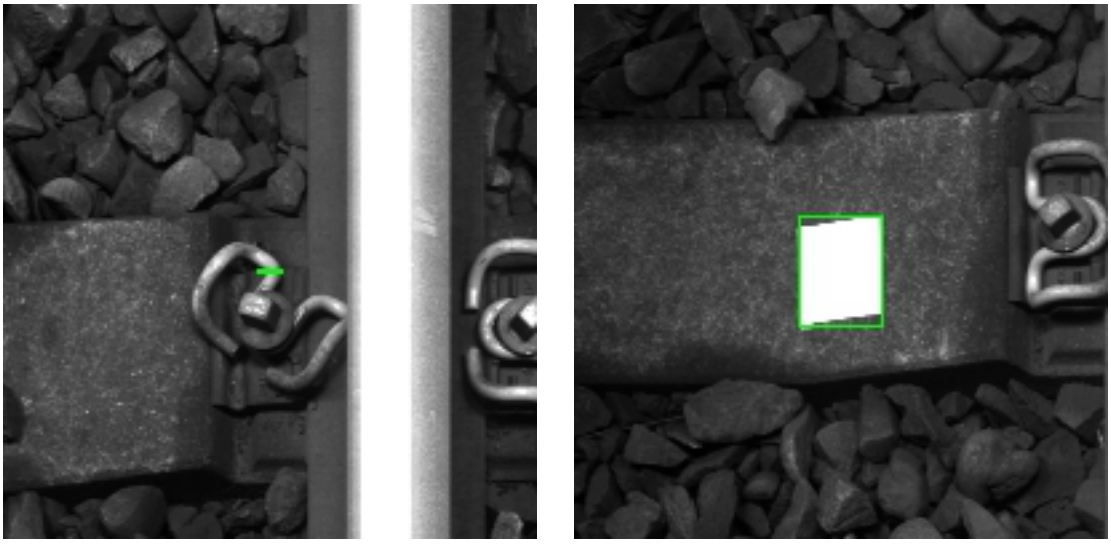


(1) Fastening (2) Fastening

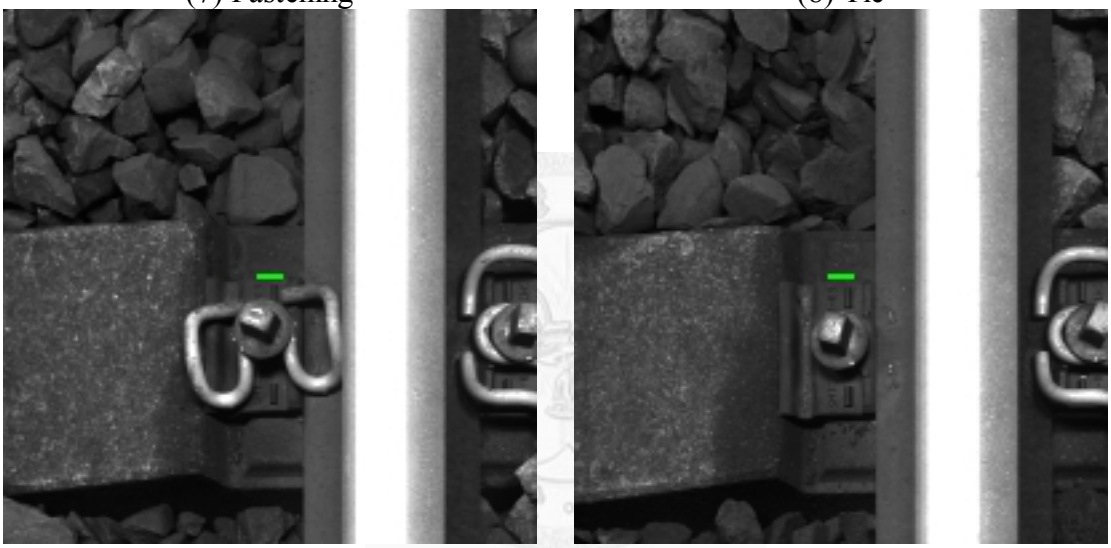
(3) Fastening (4) Fastening

(5) Fastening (6) Tie

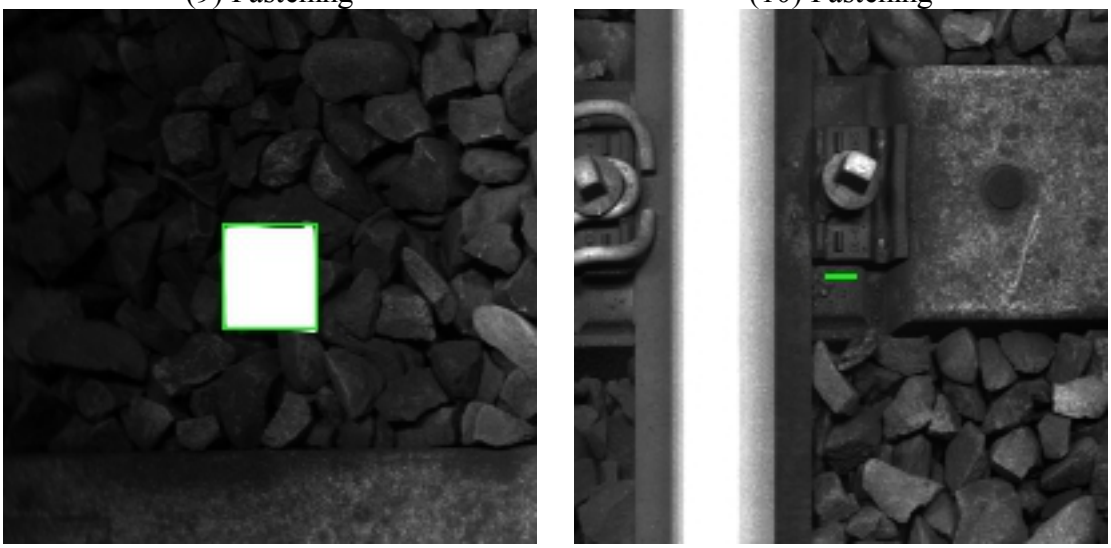
Figure 4.22 Inspected defects in the ground section. Down direction right rail (I).



(7) Fastening (8) Tie

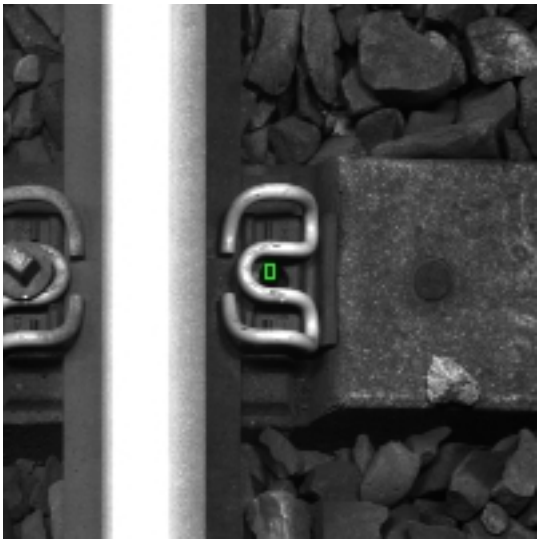


(9) Fastening (10) Fastening

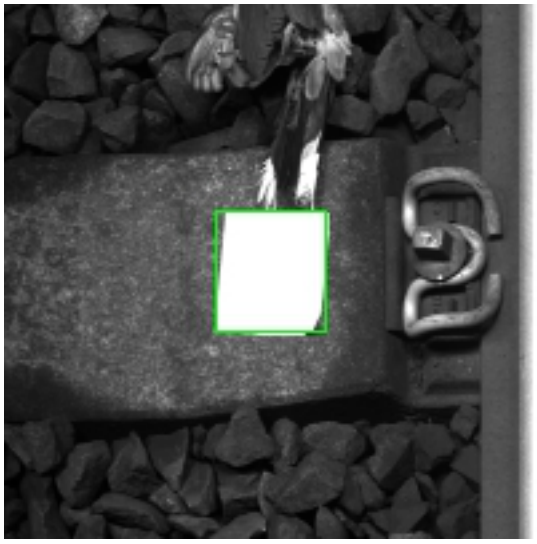


(11) Ballast (12) Fastening

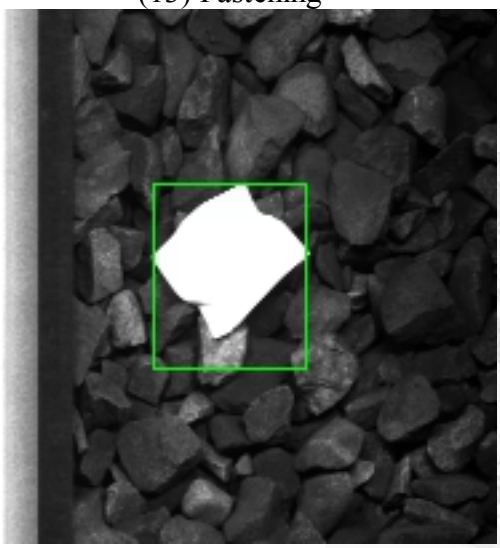
Figure 4.23 Inspected defects in the ground section. Down direction right rail (II).



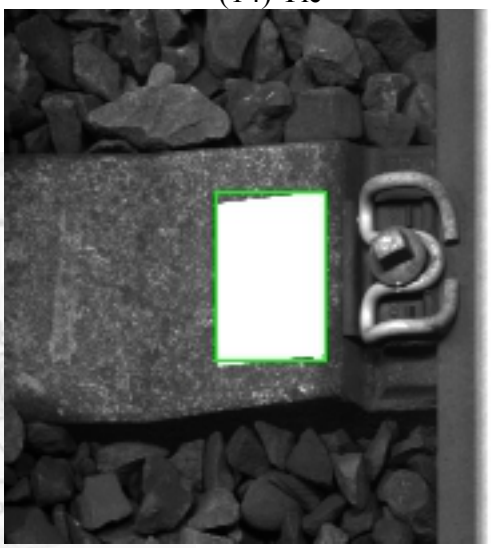
(13) Fastening



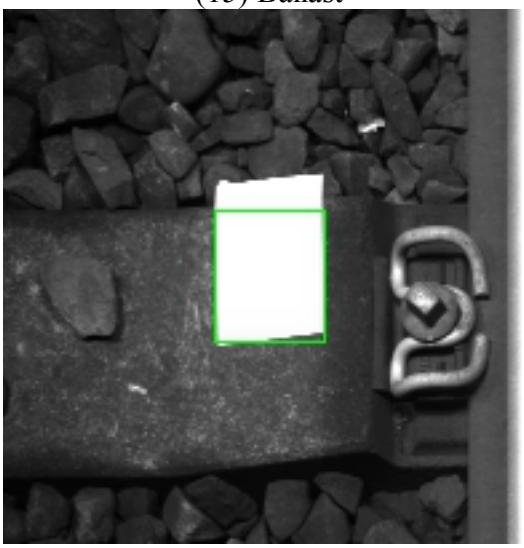
(14) Tie



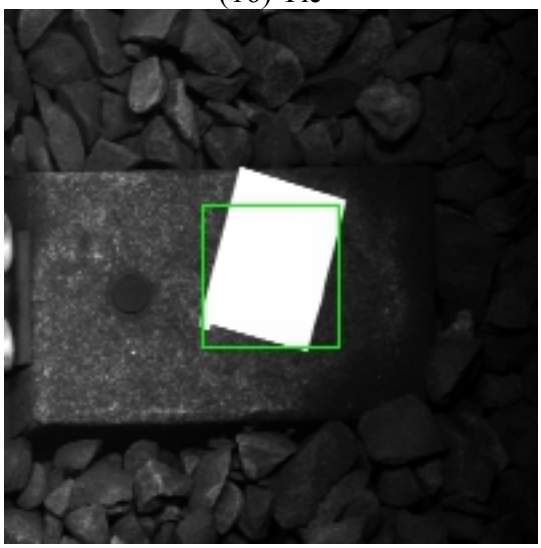
(15) Ballast



(16) Tie

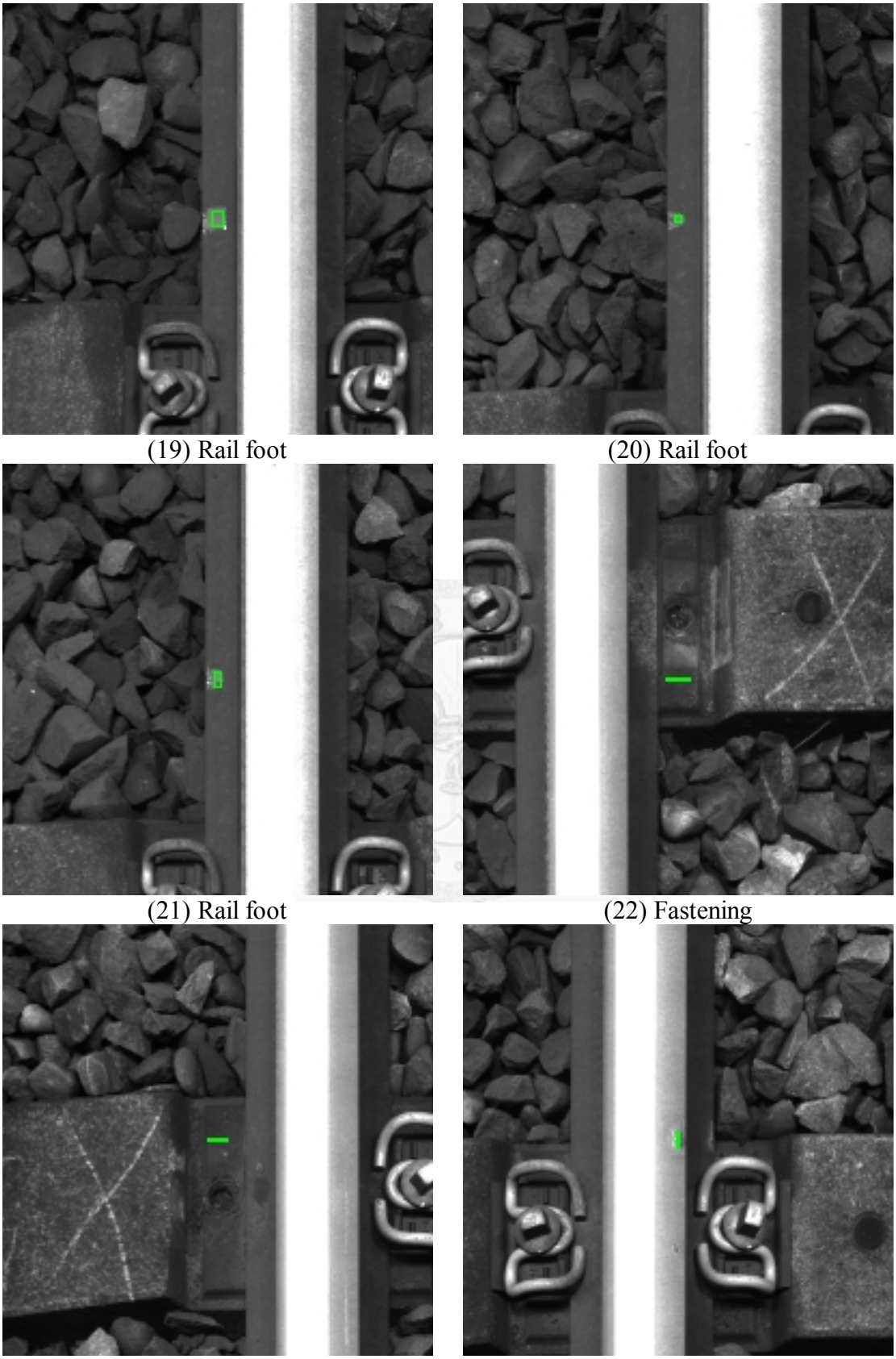


(17) Tie



(18) Tie

Figure 4.24 Inspected defects in the ground section. Down direction right rail (III).

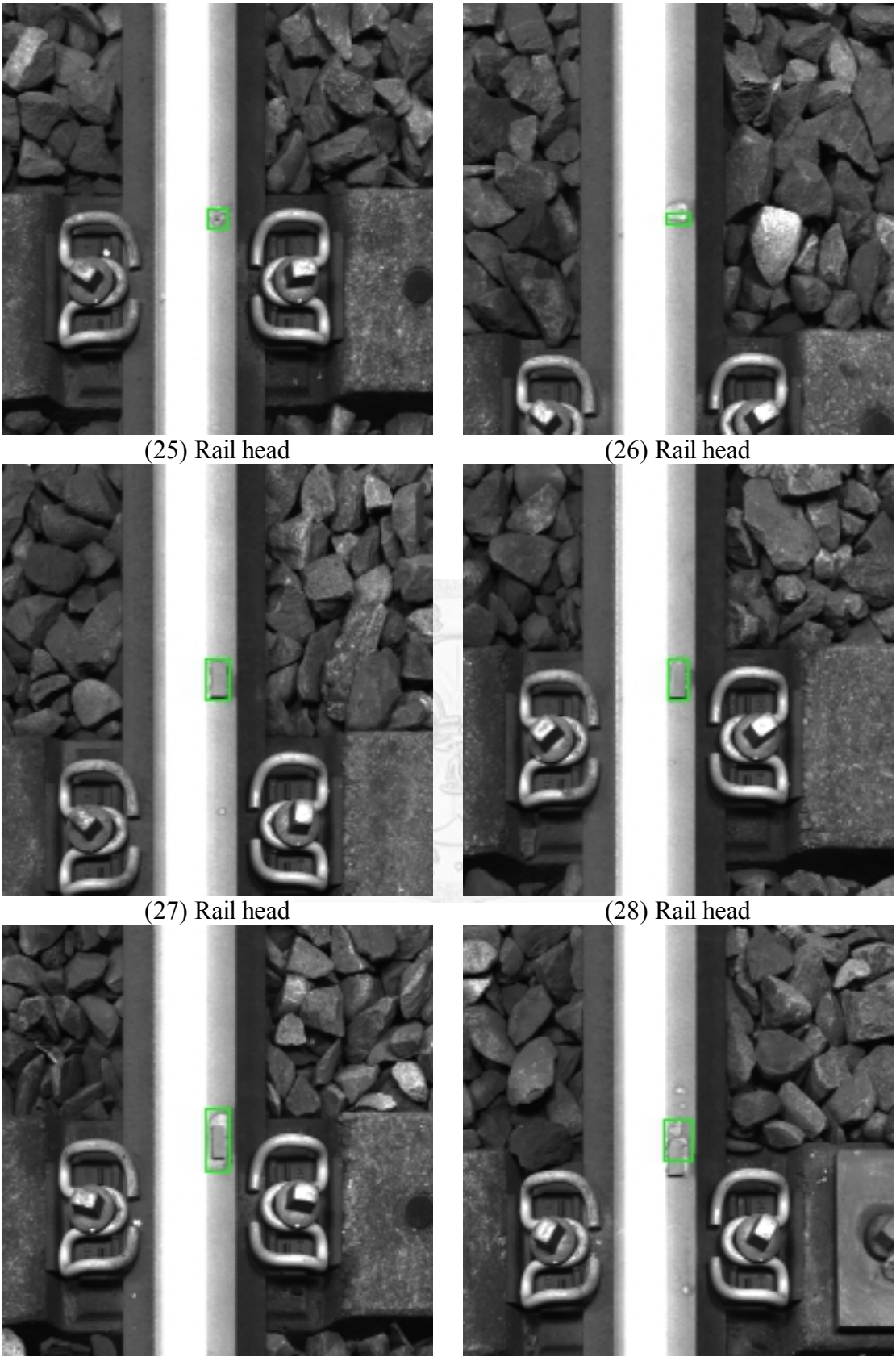


(19) Rail foot (20) Rail foot

(21) Rail foot (22) Fastening

(23) Fastening (24) Rail head

Figure 4.25 Inspected defects in the ground section. Down direction right rail (IV).

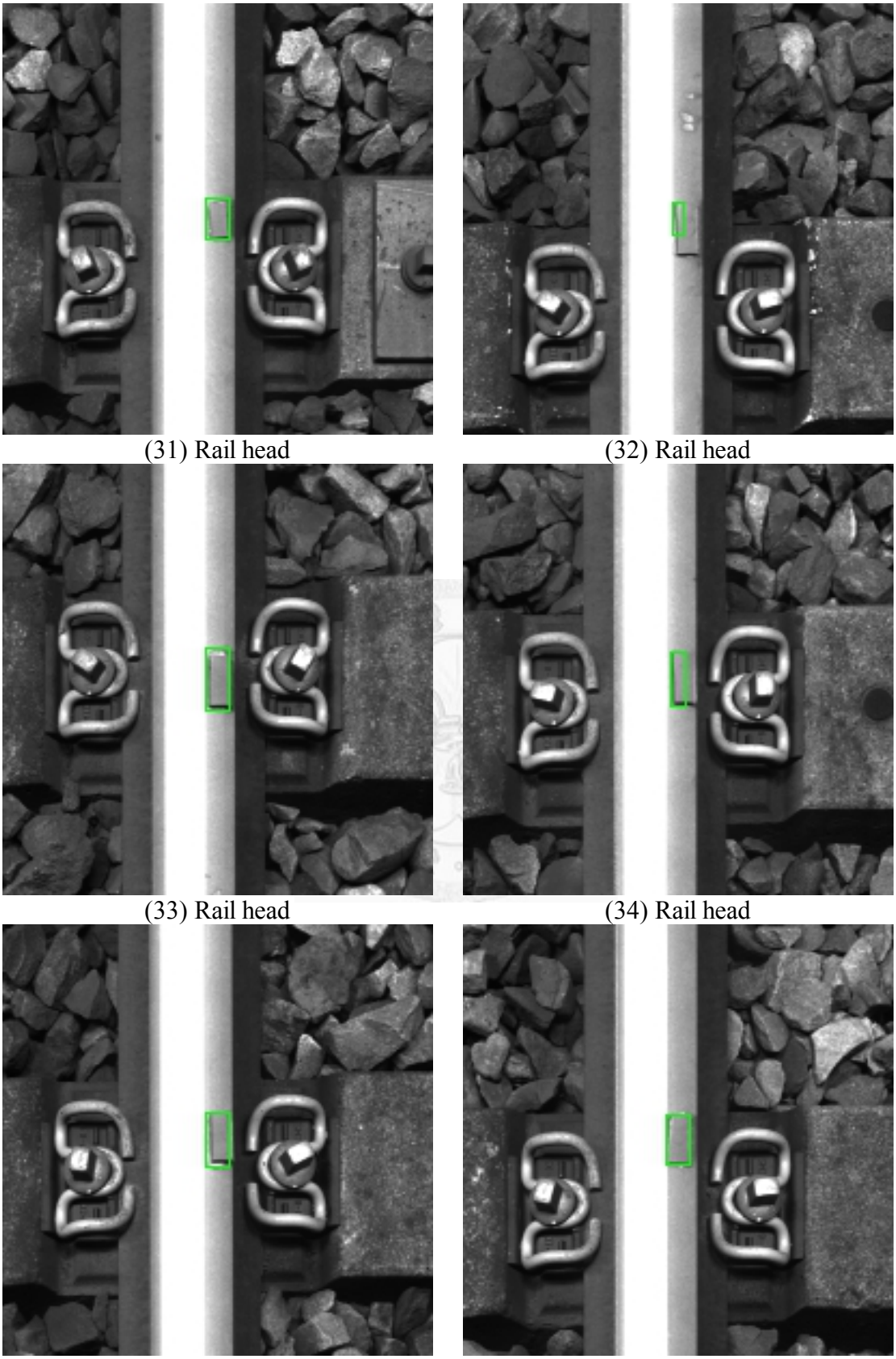


(25) Rail head (26) Rail head

(27) Rail head (28) Rail head

(29) Rail head (30) Rail head

Figure 4.26 Inspected defects in the ground section. Down direction right rail (V).

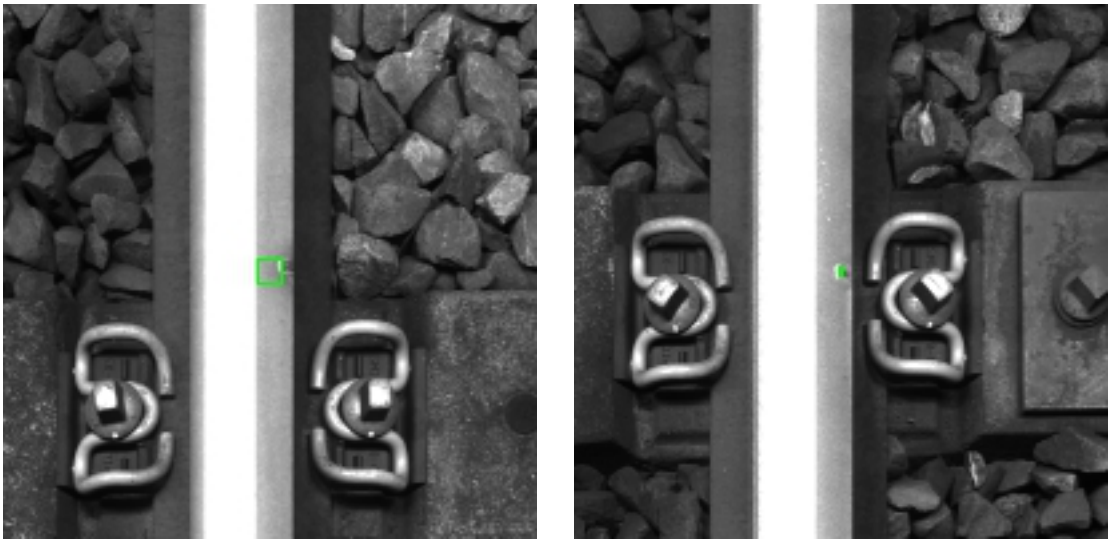


(31) Rail head (32) Rail head

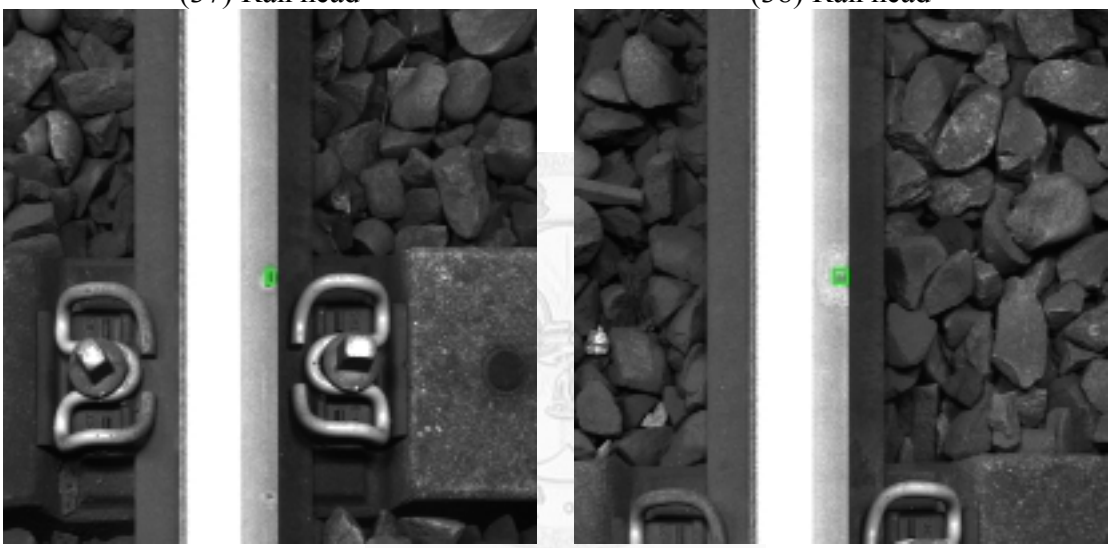
(33) Rail head (34) Rail head

(35) Rail head (36) Rail head

Figure 4.27 Inspected defects in the ground section. Down direction right rail (VI).



(37) Rail head (38) Rail head



(39) Rail head (40) Rail head

Figure 4.28 Inspected defects in the ground section. Down direction right rail (VII).

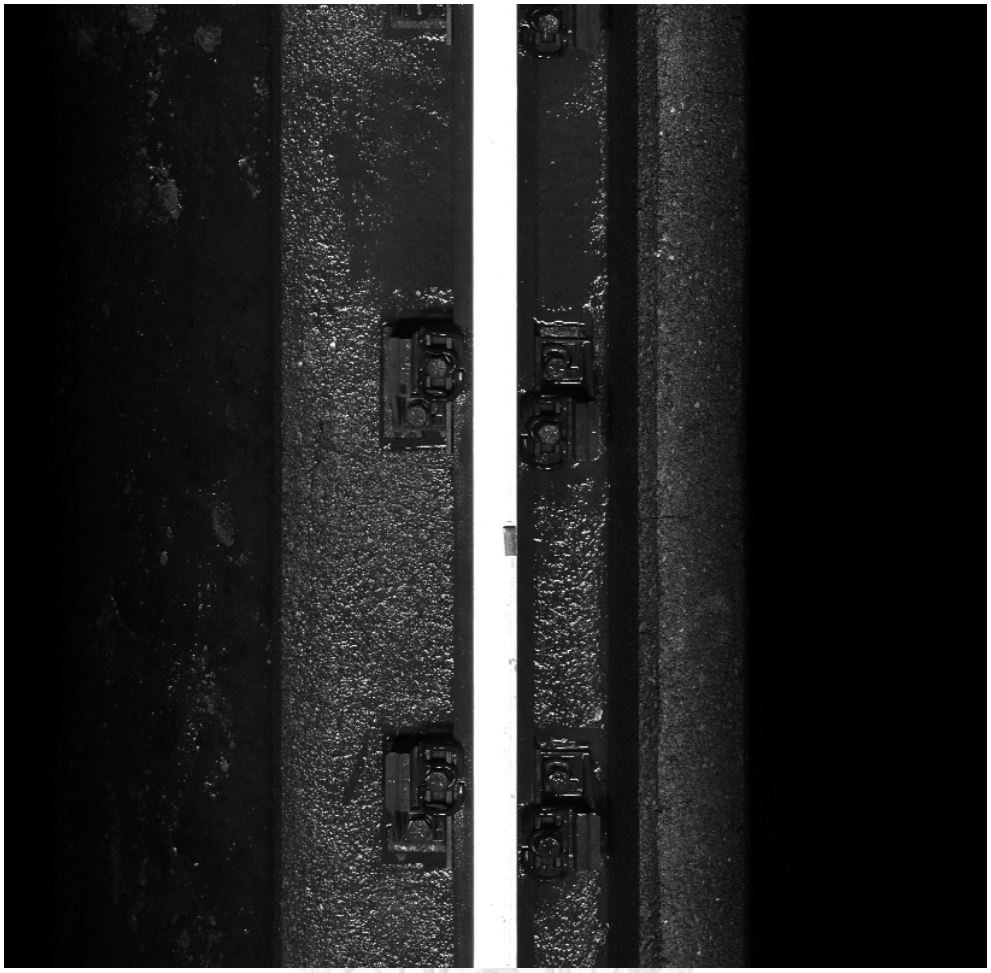


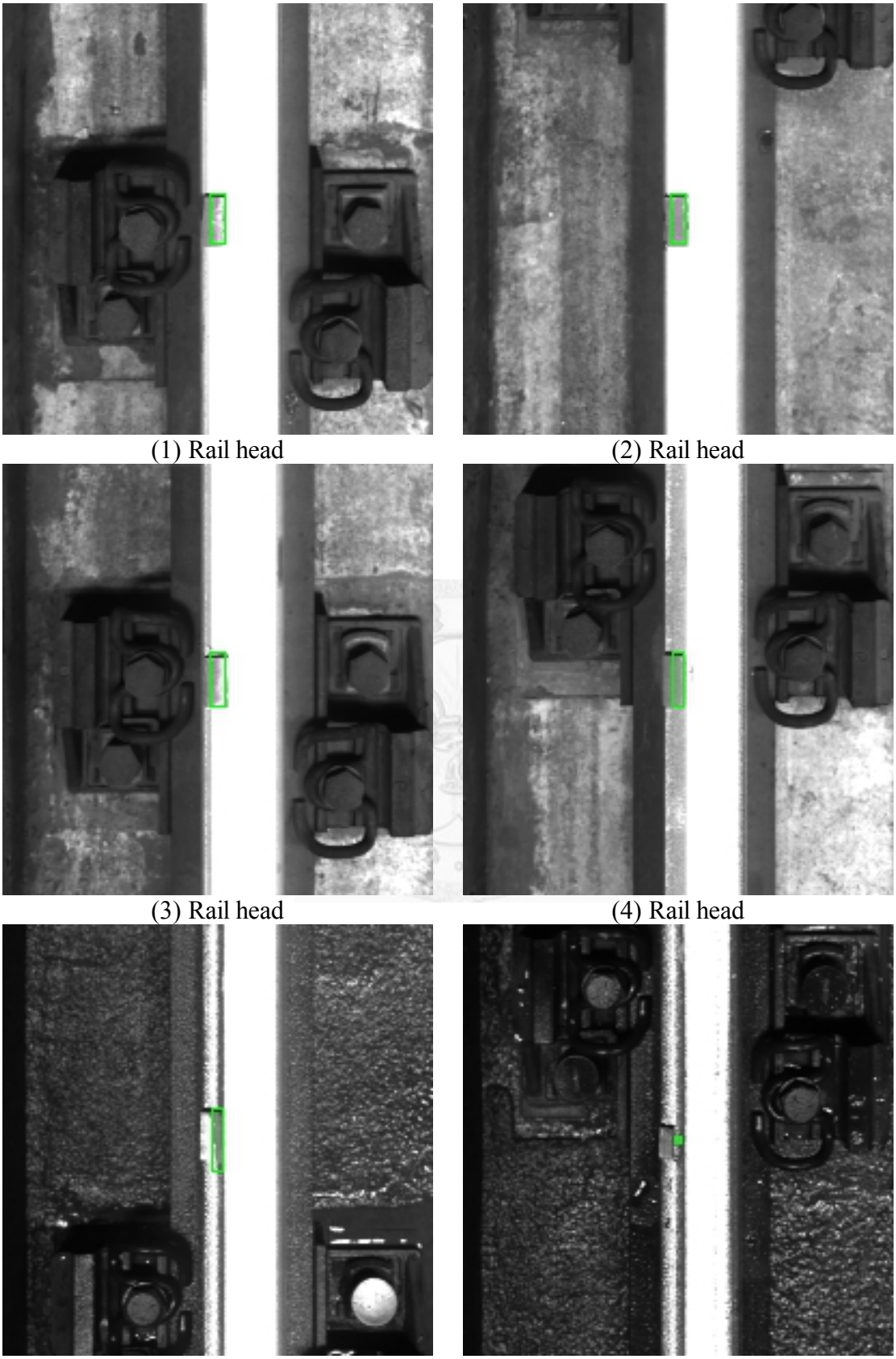
Figure 4.29 The sample page of the elevated section.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 45 | 34 | 75.56% |
| Right Rail | 47 | 36 | 76.60% |
| Total | 92 | 70 | 76.09% |

Figure 4.30 The inspection statistics for the elevated section up direction.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 47 | 37 | 78.72% |
| Right Rail | 50 | 40 | 80.00% |
| Total | 97 | 77 | 79.38% |

Figure 4.31 The inspection statistics for the elevated section down direction.

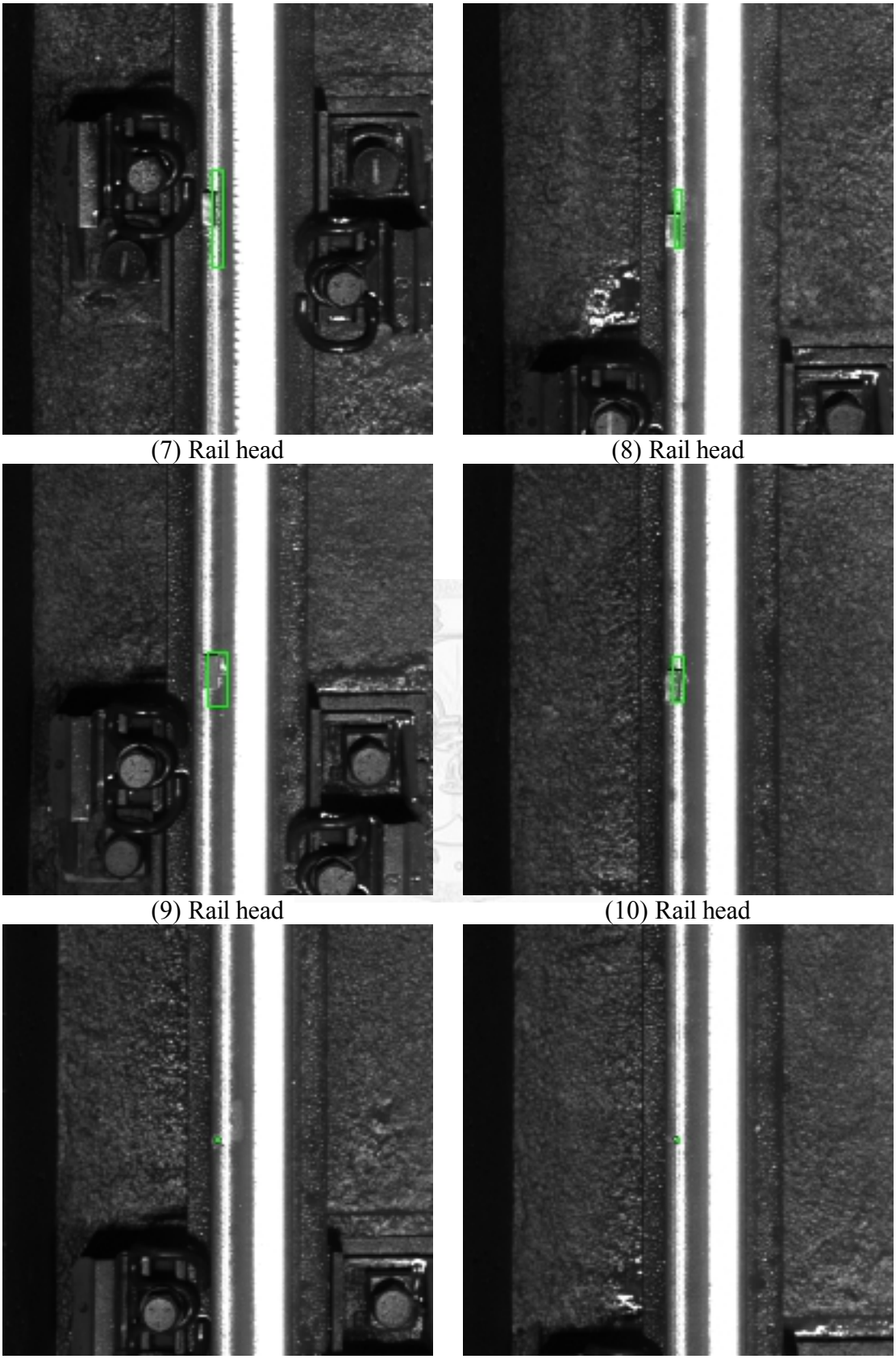


(1) Rail head (2) Rail head

(3) Rail head (4) Rail head

(5) Rail head (6) Rail head

Figure 4.32 Inspected defects in the elevated section after rain. Up direction left rail (I).

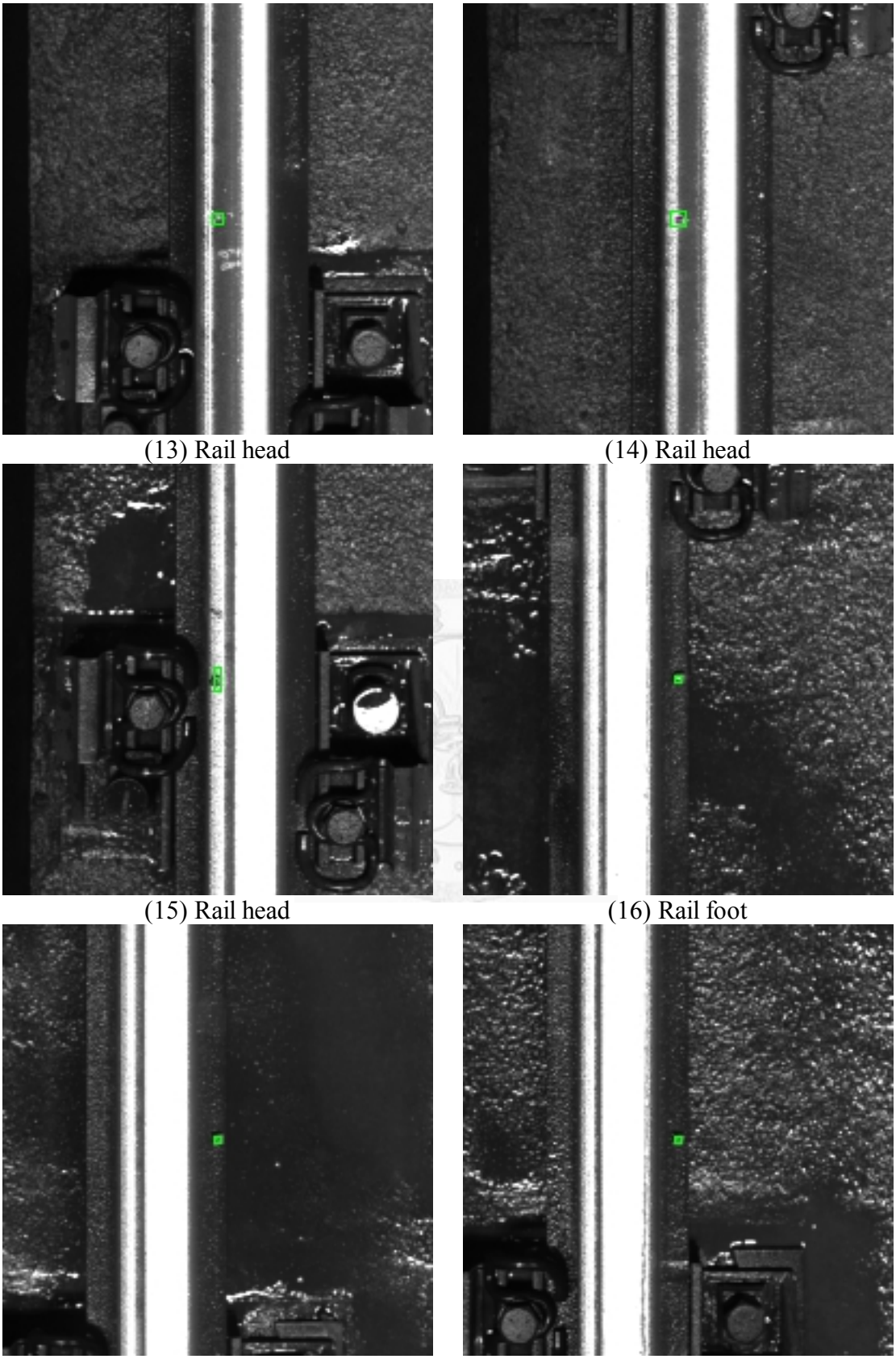


(7) Rail head (8) Rail head

(9) Rail head (10) Rail head

(11) Rail head (12) Rail head

Figure 4.33 Inspected defects in the elevated section after rain. Up direction left rail (II).

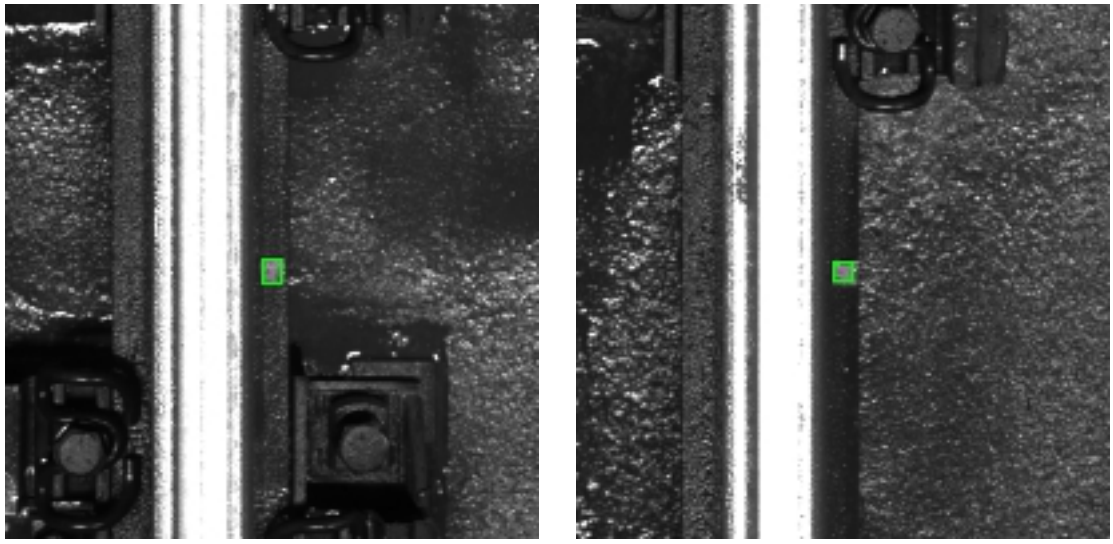


(13) Rail head (14) Rail head

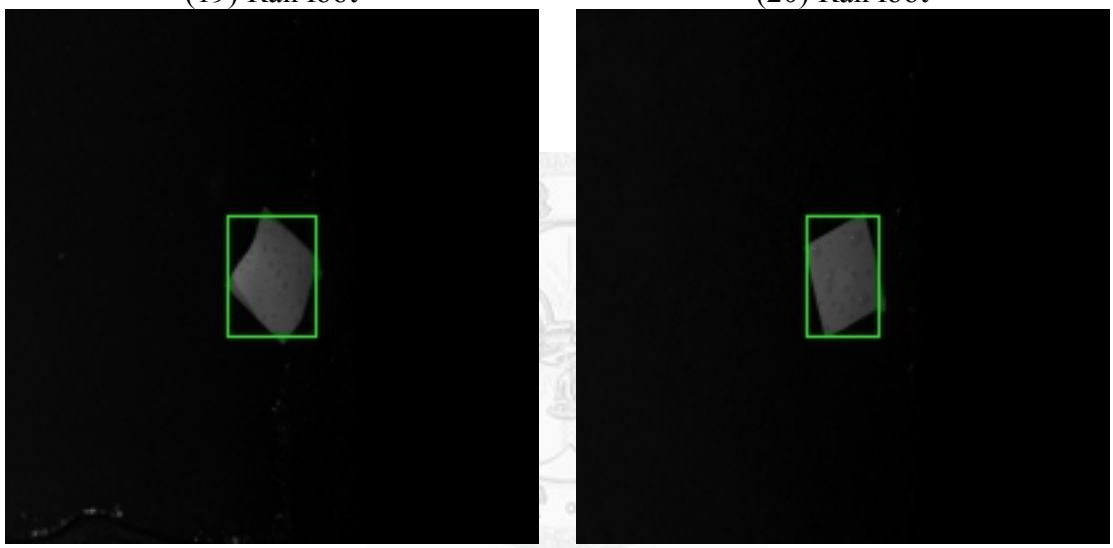
(15) Rail head (16) Rail foot

(17) Rail foot (18) Rail foot

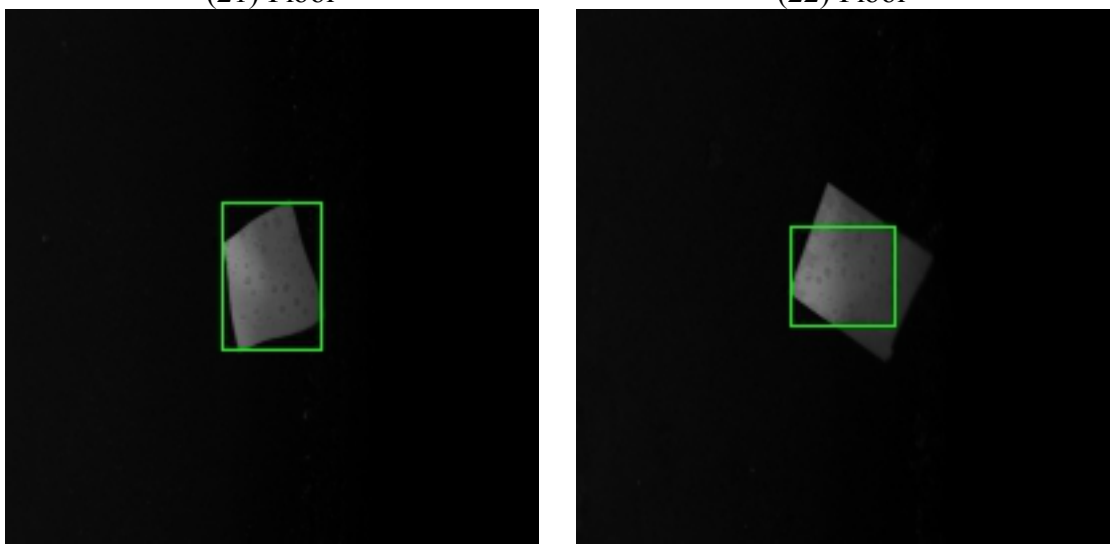
Figure 4.34 Inspected defects in the elevated section after rain. Up direction left rail (III).



(19) Rail foot (20) Rail foot

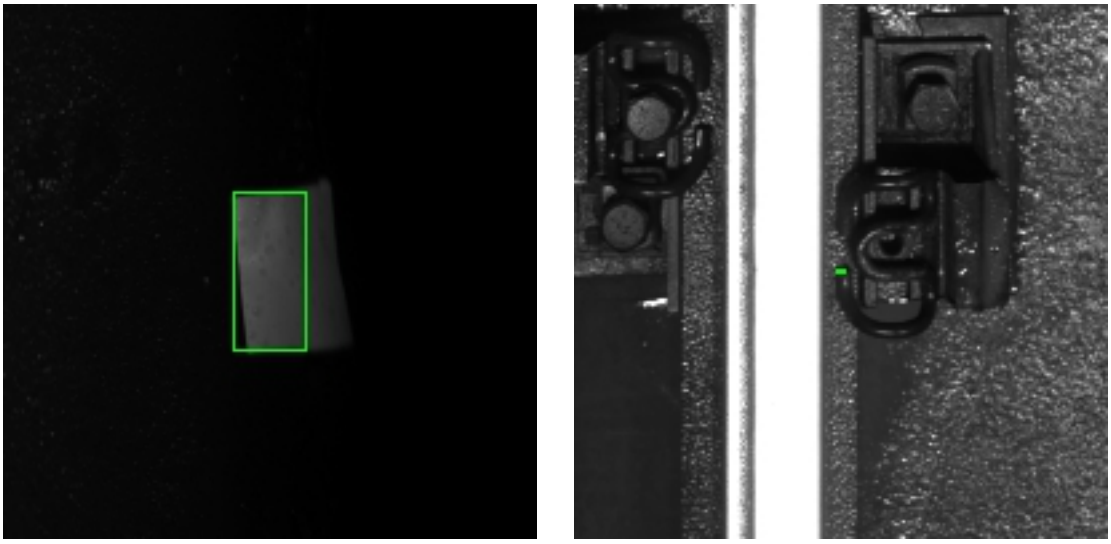


(21) Floor (22) Floor

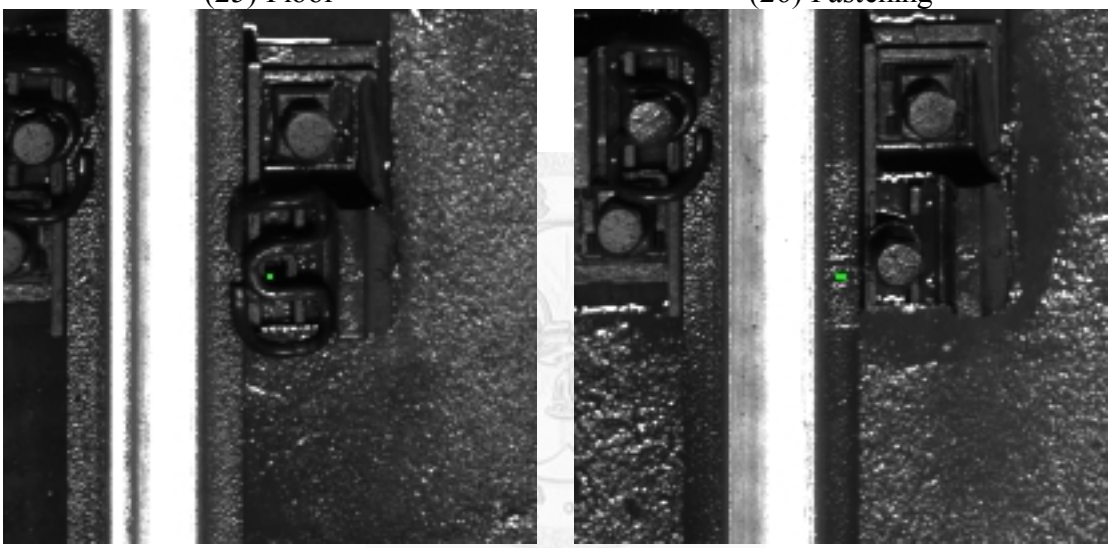


(23) Floor (24) Floor

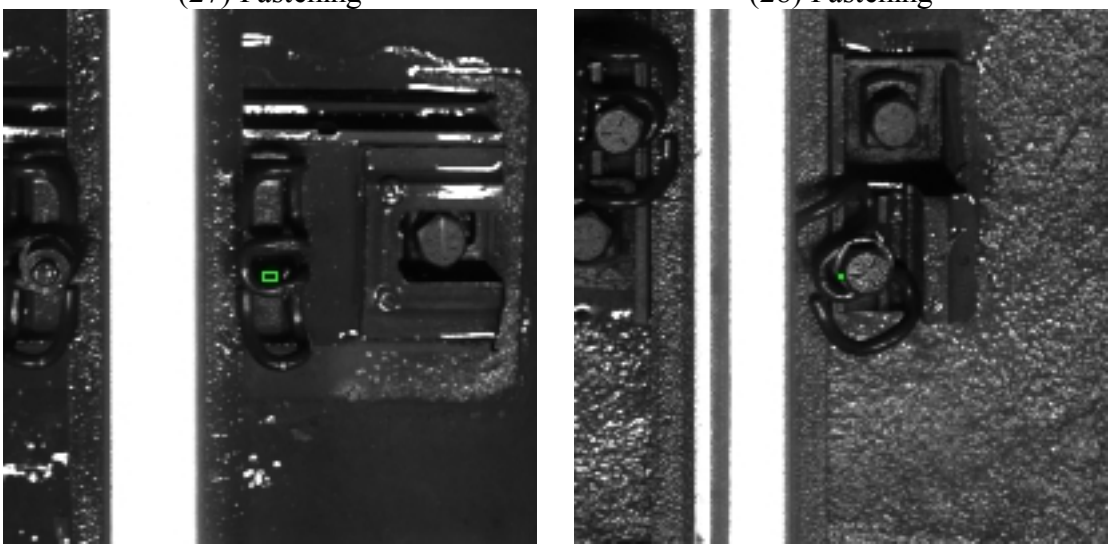
Figure 4.35 Inspected defects in the elevated section after rain. Up direction left rail (IV).



(25) Floor (26) Fastening

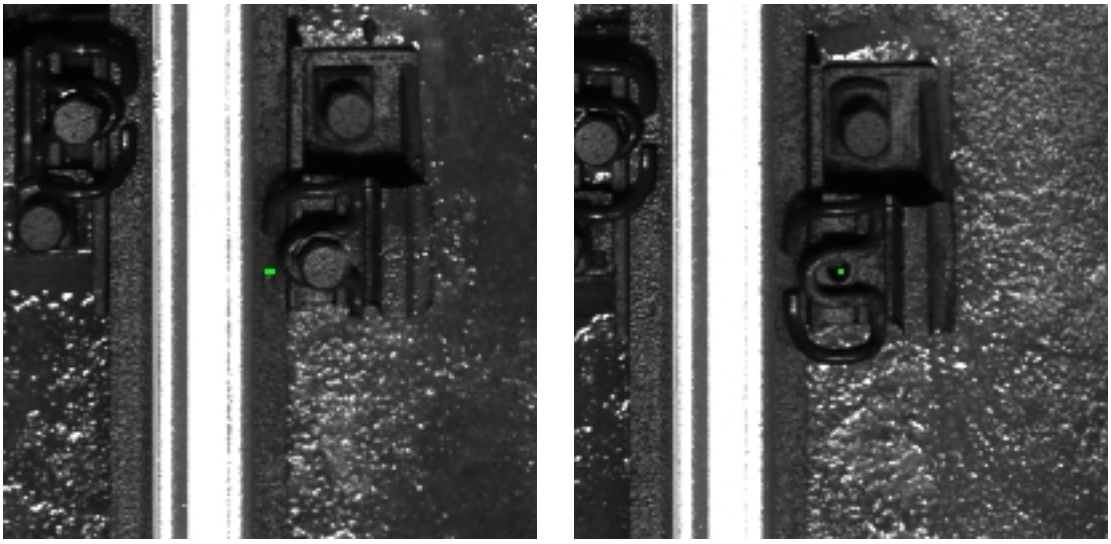


(27) Fastening (28) Fastening

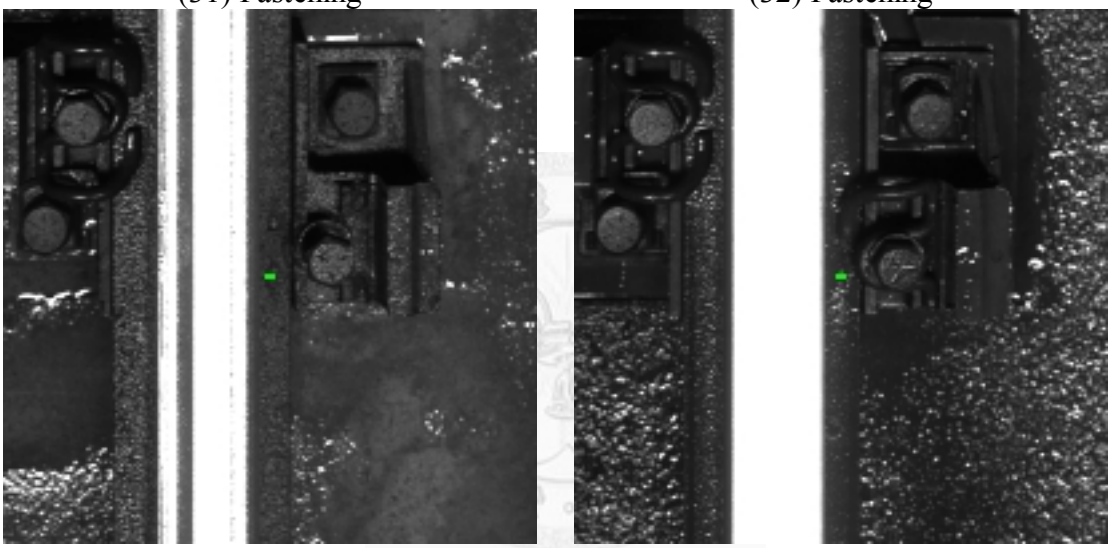


(29) Fastening (30) Fastening

Figure 4.36 Inspected defects in the elevated section after rain. Up direction left rail (V).

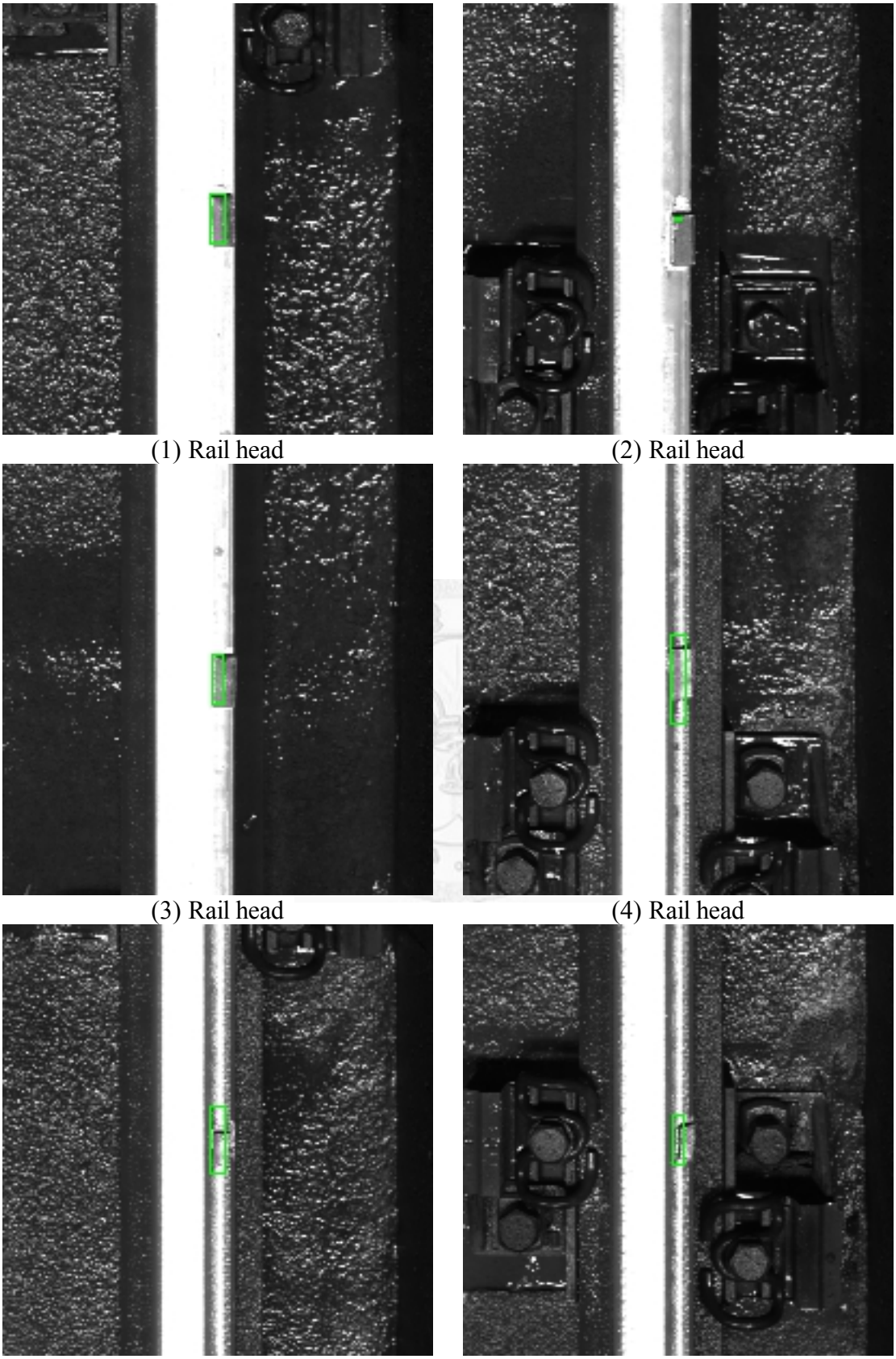


(31) Fastening (32) Fastening



(33) Fastening (34) Fastening

Figure 4.37 Inspected defects in the elevated section after rain. Up direction left rail (VI).

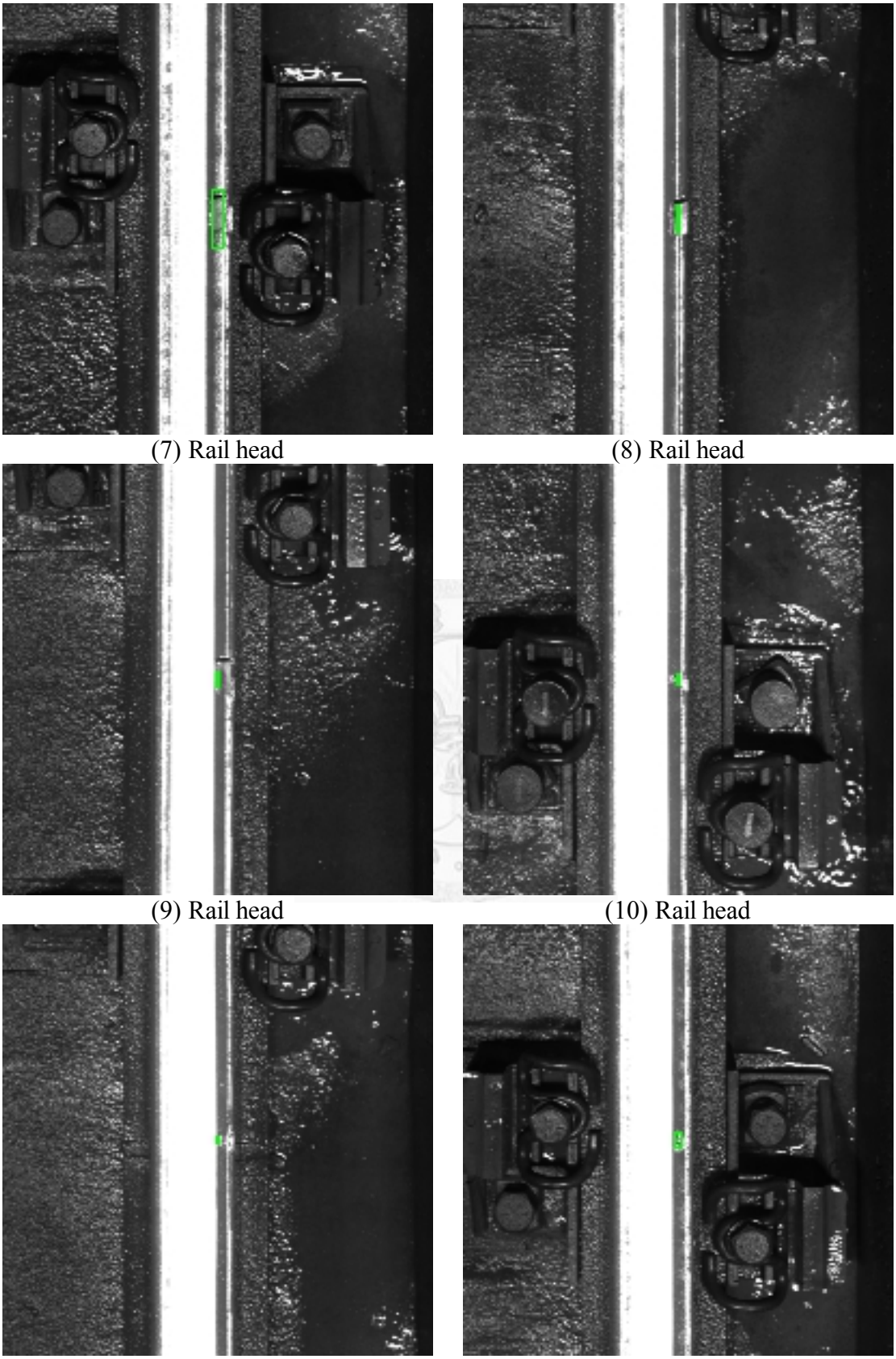


(1) Rail head (2) Rail head

(3) Rail head (4) Rail head

(5) Rail head (6) Rail head

Figure 4.38 Inspected defects in the elevated section after rain. Up direction right rail (I).

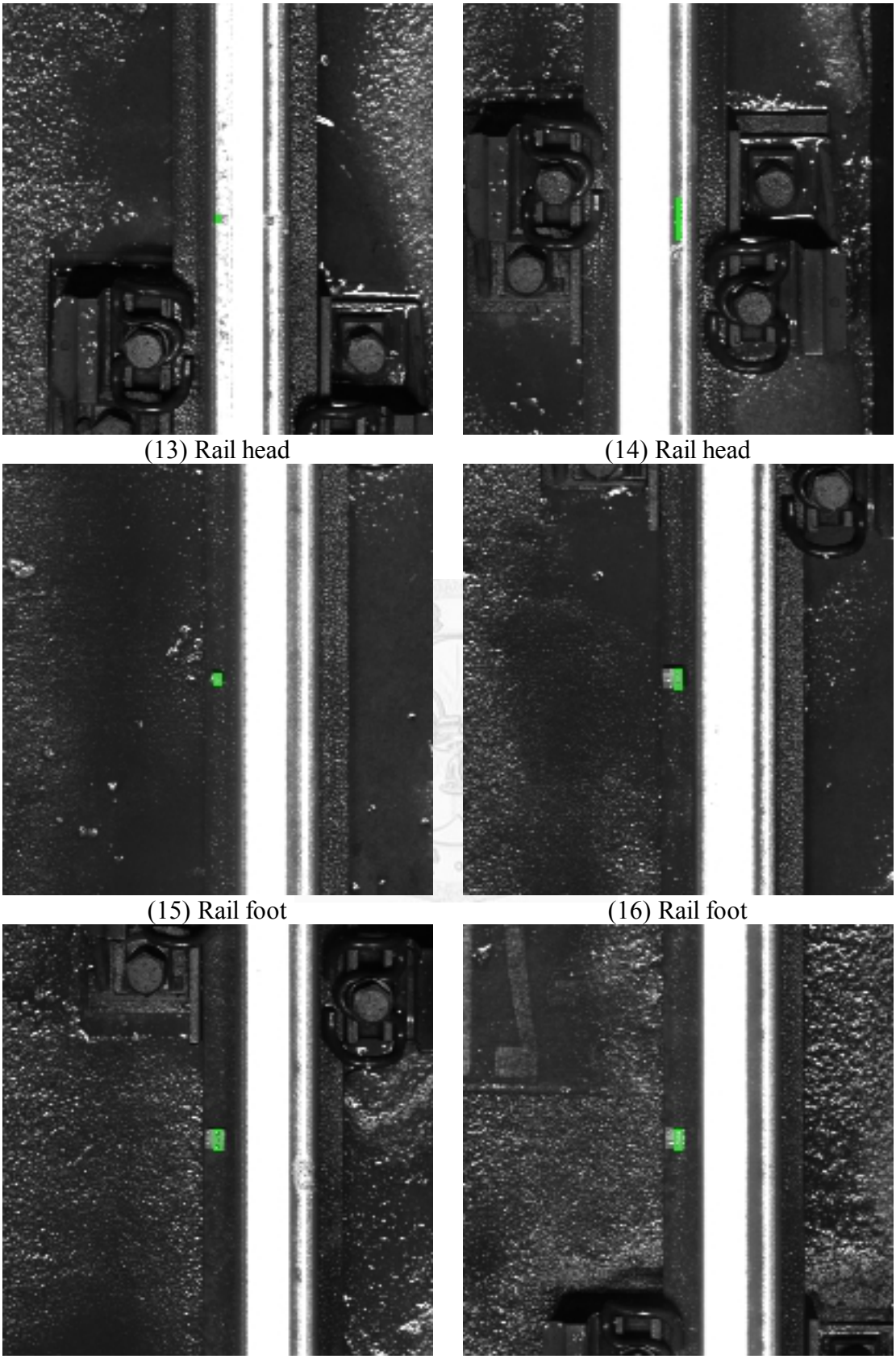


(7) Rail head (8) Rail head

(9) Rail head (10) Rail head

(11) Rail head (12) Rail head

Figure 4.39 Inspected defects in the elevated section after rain. Up direction right rail (II).

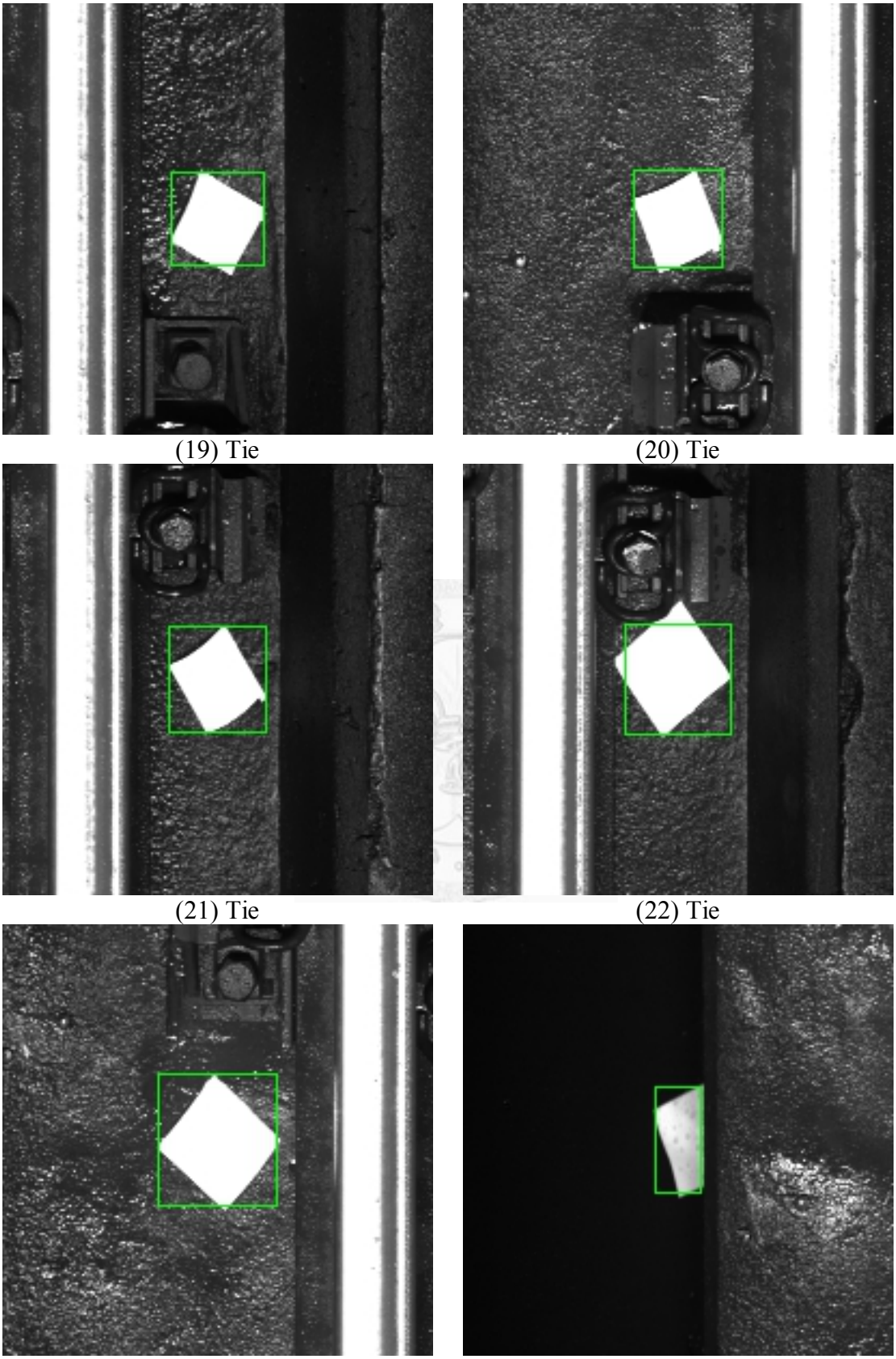


(13) Rail head (14) Rail head

(15) Rail foot (16) Rail foot

(17) Rail foot (18) Rail foot

Figure 4.40 Inspected defects in the elevated section after rain. Up direction right rail (III).

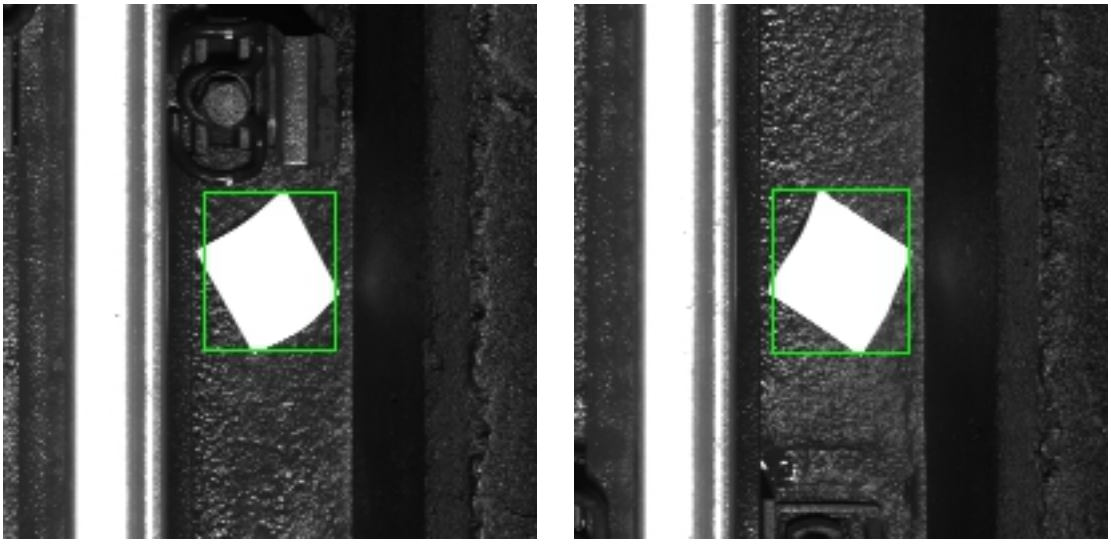


(19) Tie (20) Tie

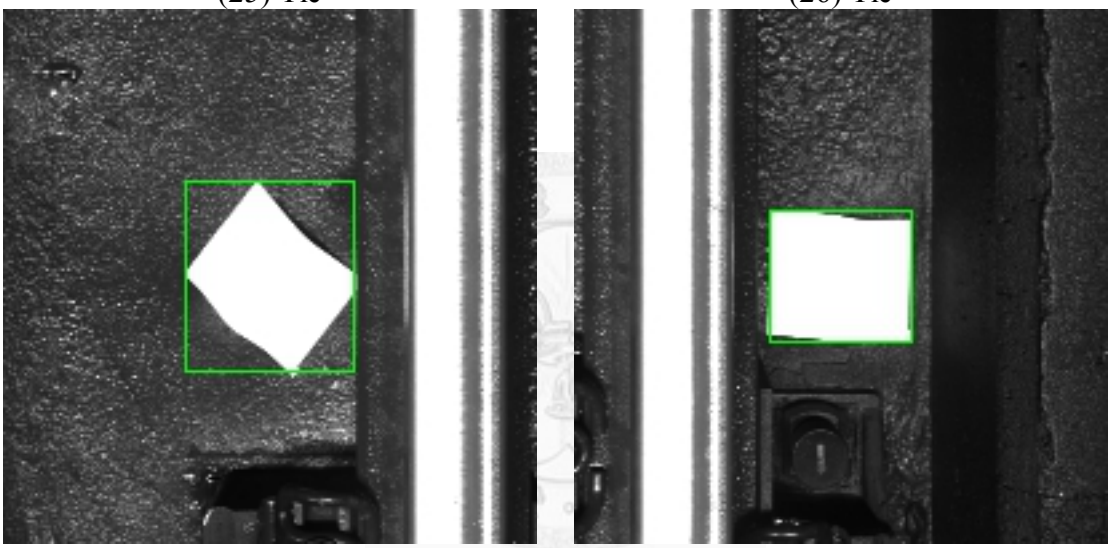
(21) Tie (22) Tie

(23) Tie (24) Floor

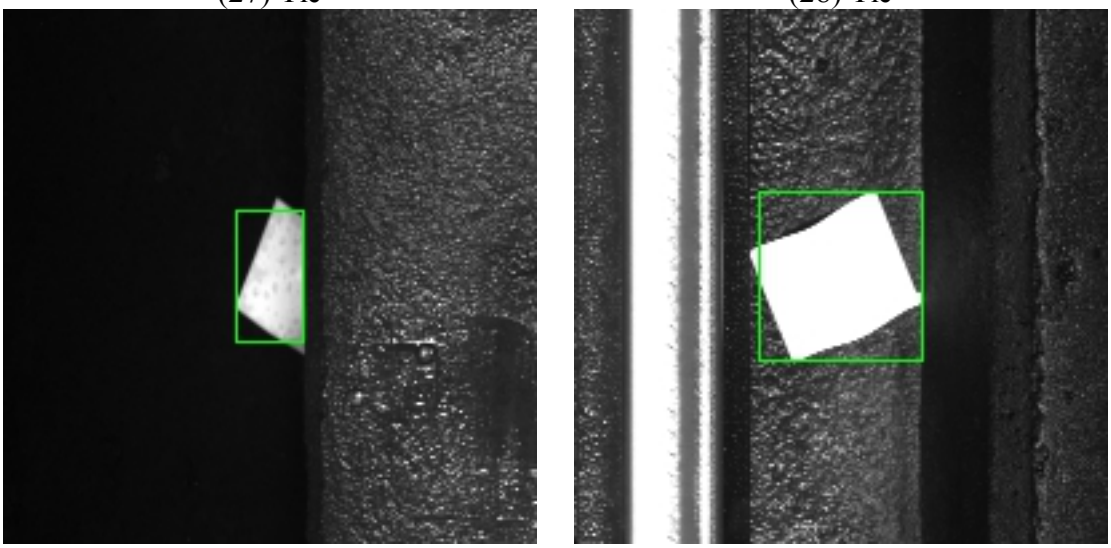
Figure 4.41 Inspected defects in the elevated section after rain. Up direction right rail (IV).



(25) Tie (26) Tie

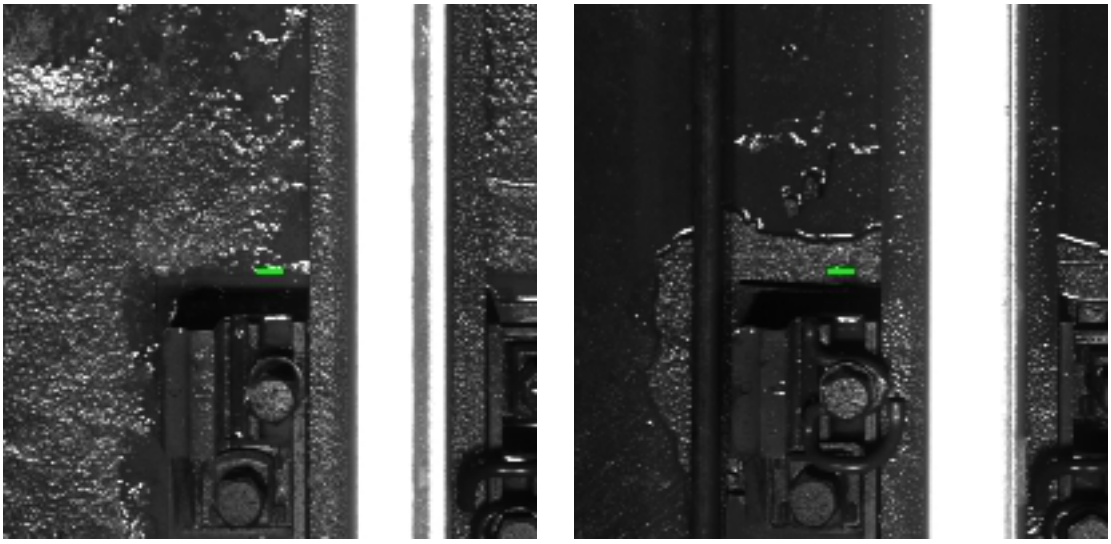


(27) Tie (28) Tie

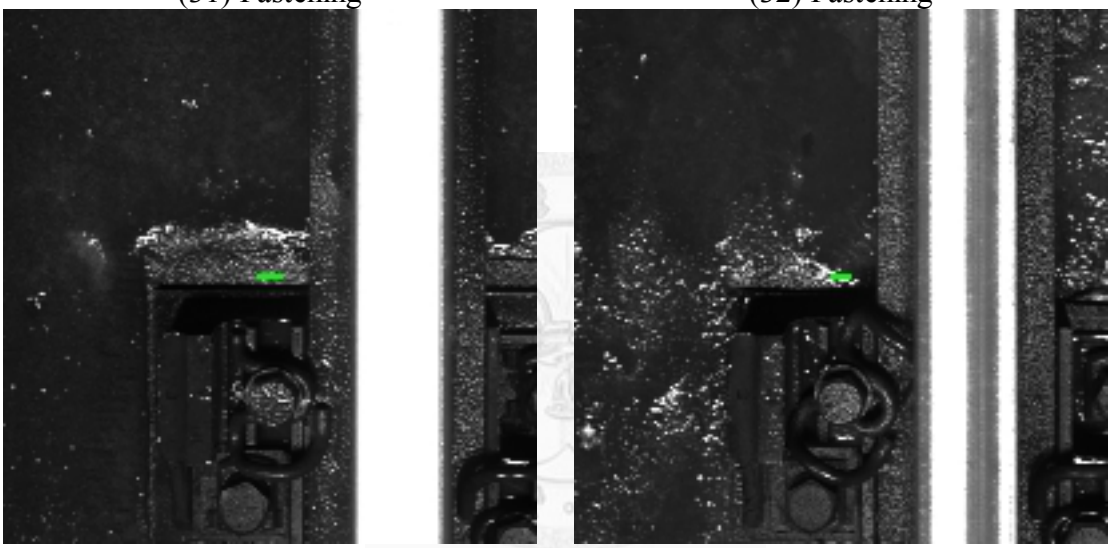


(29) Floor (30) Tie

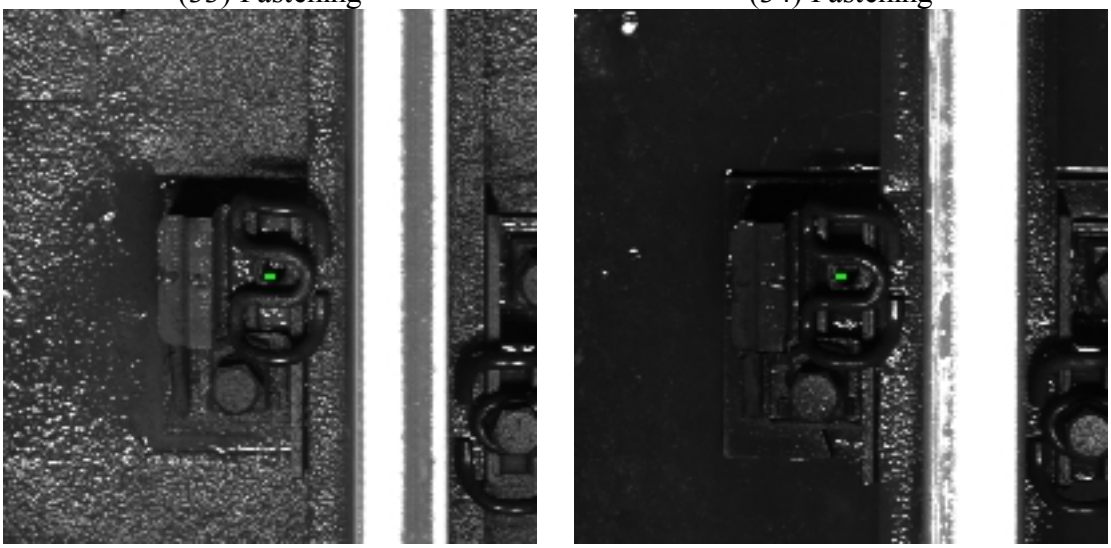
Figure 4.42 Inspected defects in the elevated section after rain. Up direction right rail (V).



(31) Fastening (32) Fastening

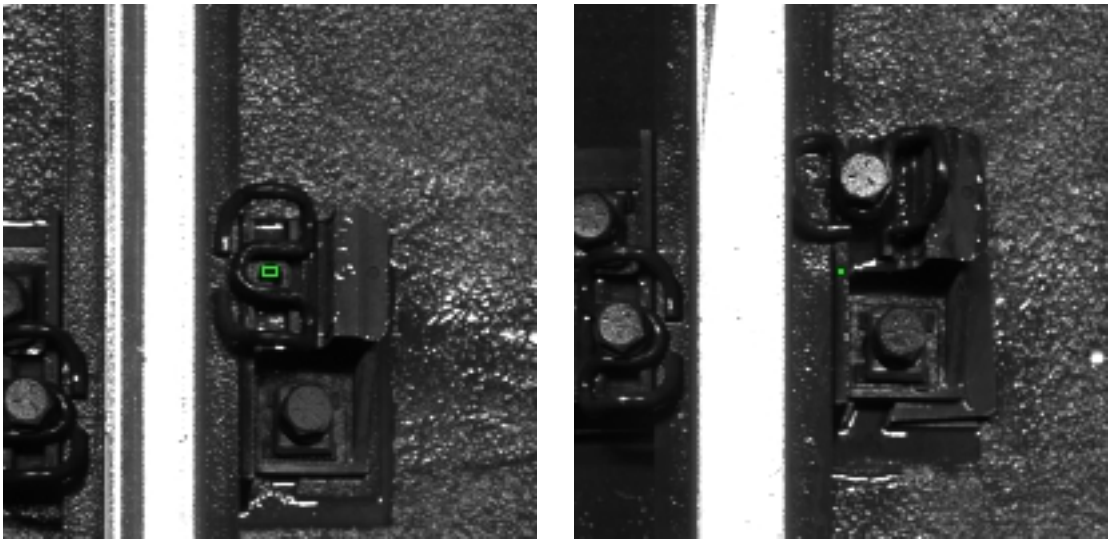


(33) Fastening (34) Fastening

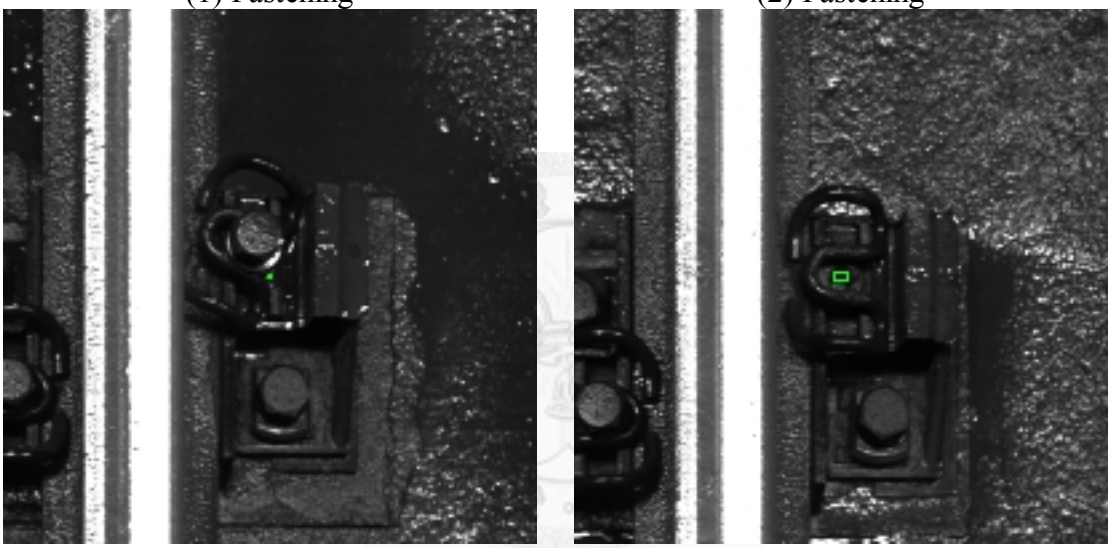


(35) Fastening (36) Fastening

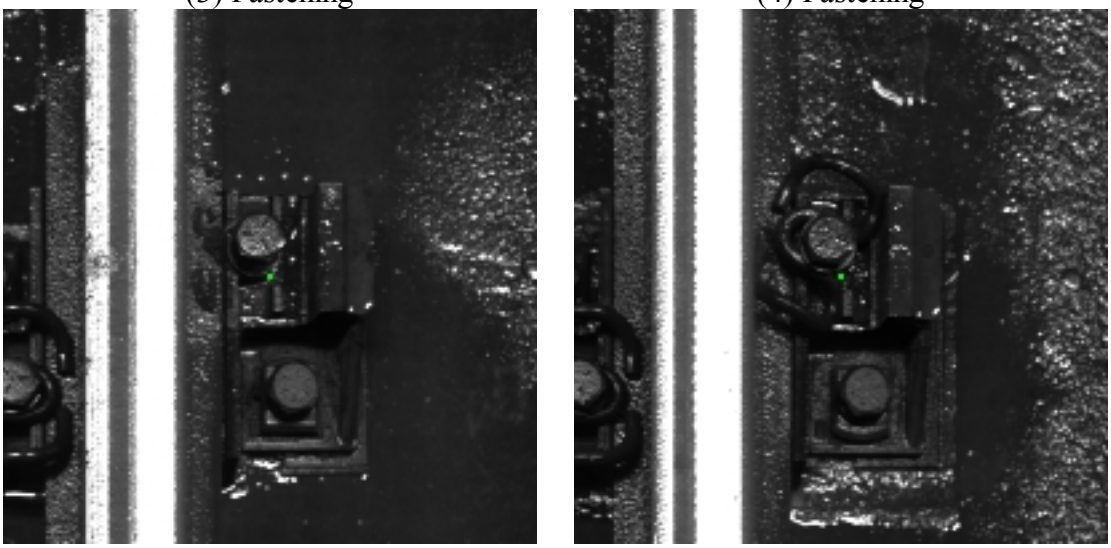
Figure 4.43 Inspected defects in the elevated section after rain. Up direction right rail (VI).



(1) Fastening (2) Fastening

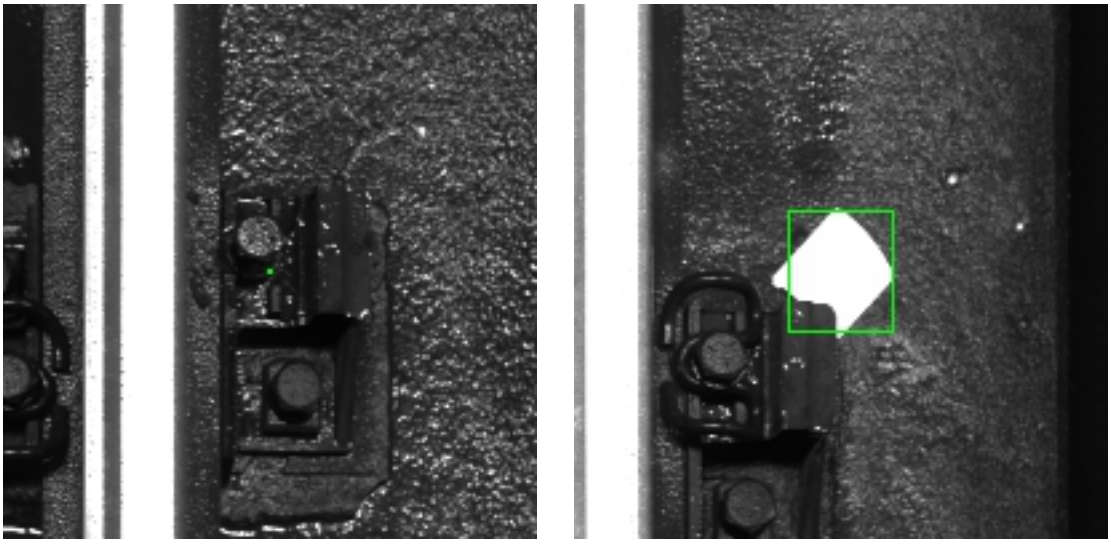


(3) Fastening (4) Fastening

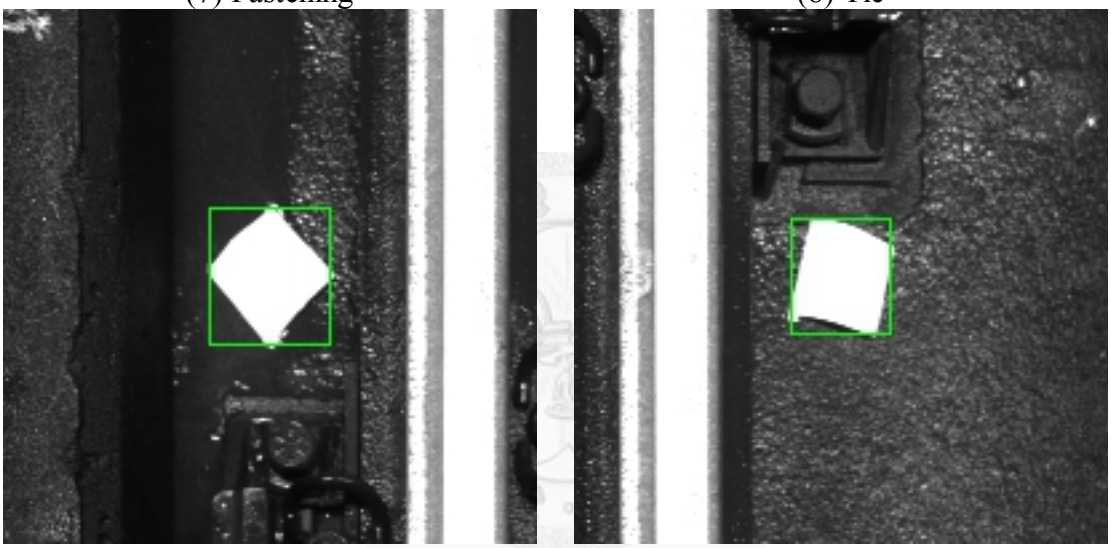


(5) Fastening (6) Fastening

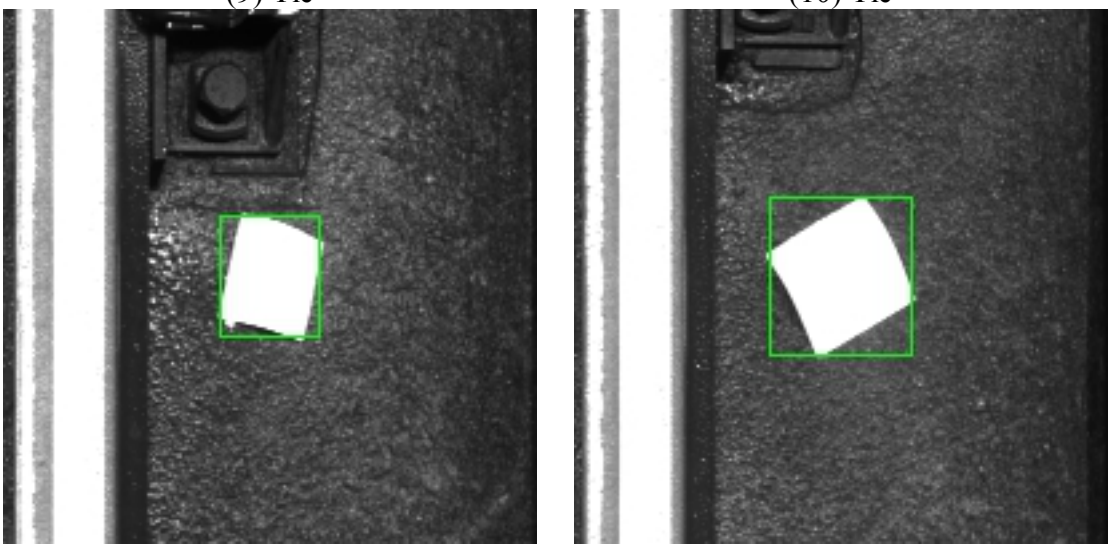
Figure 4.44 Inspected defects in the elevated section after rain. Down direction left rail (I).



(7) Fastening (8) Tie

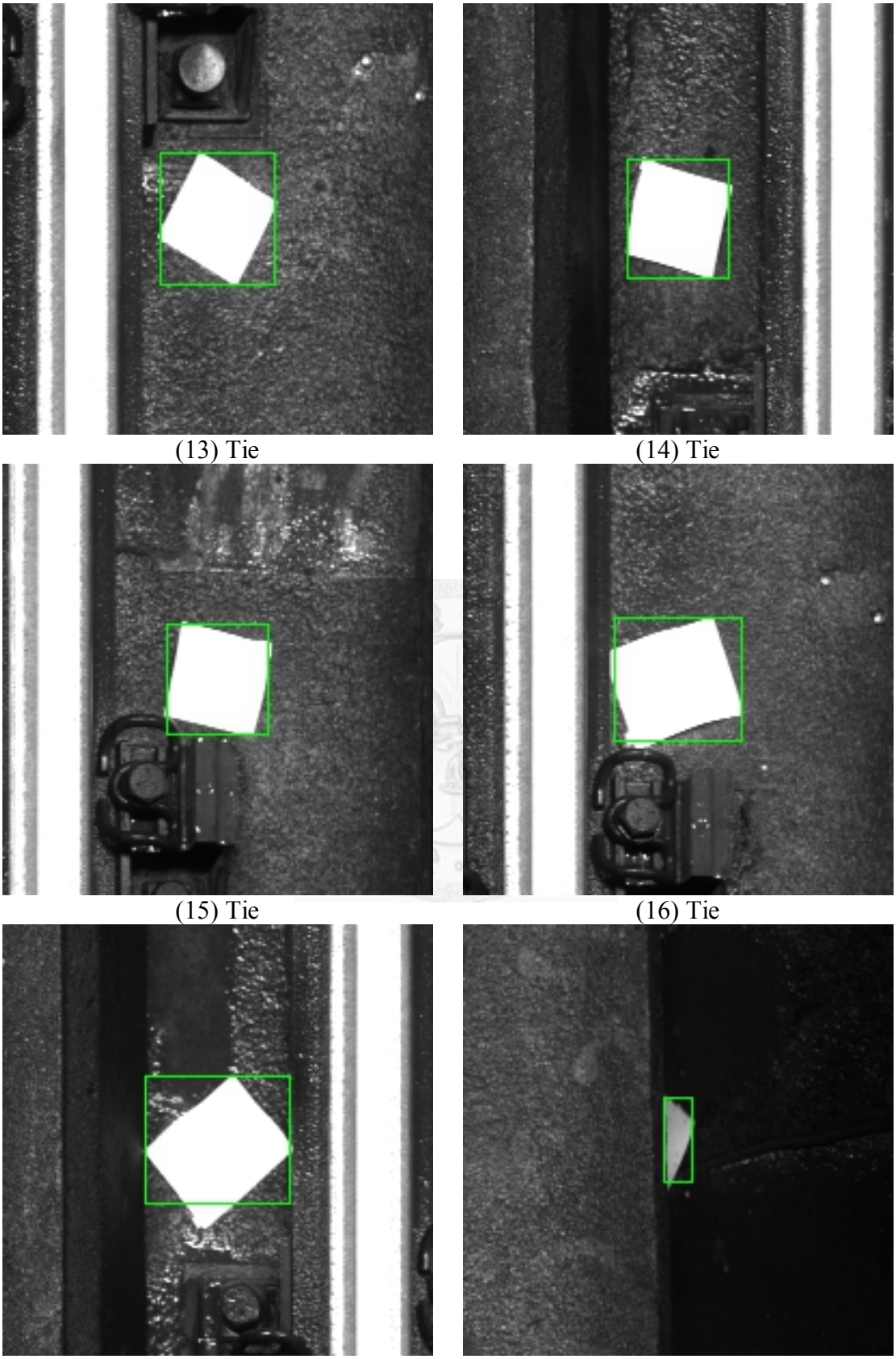


(9) Tie (10) Tie



(11) Tie (12) Tie

Figure 4.45 Inspected defects in the elevated section after rain. Down direction left rail (II).

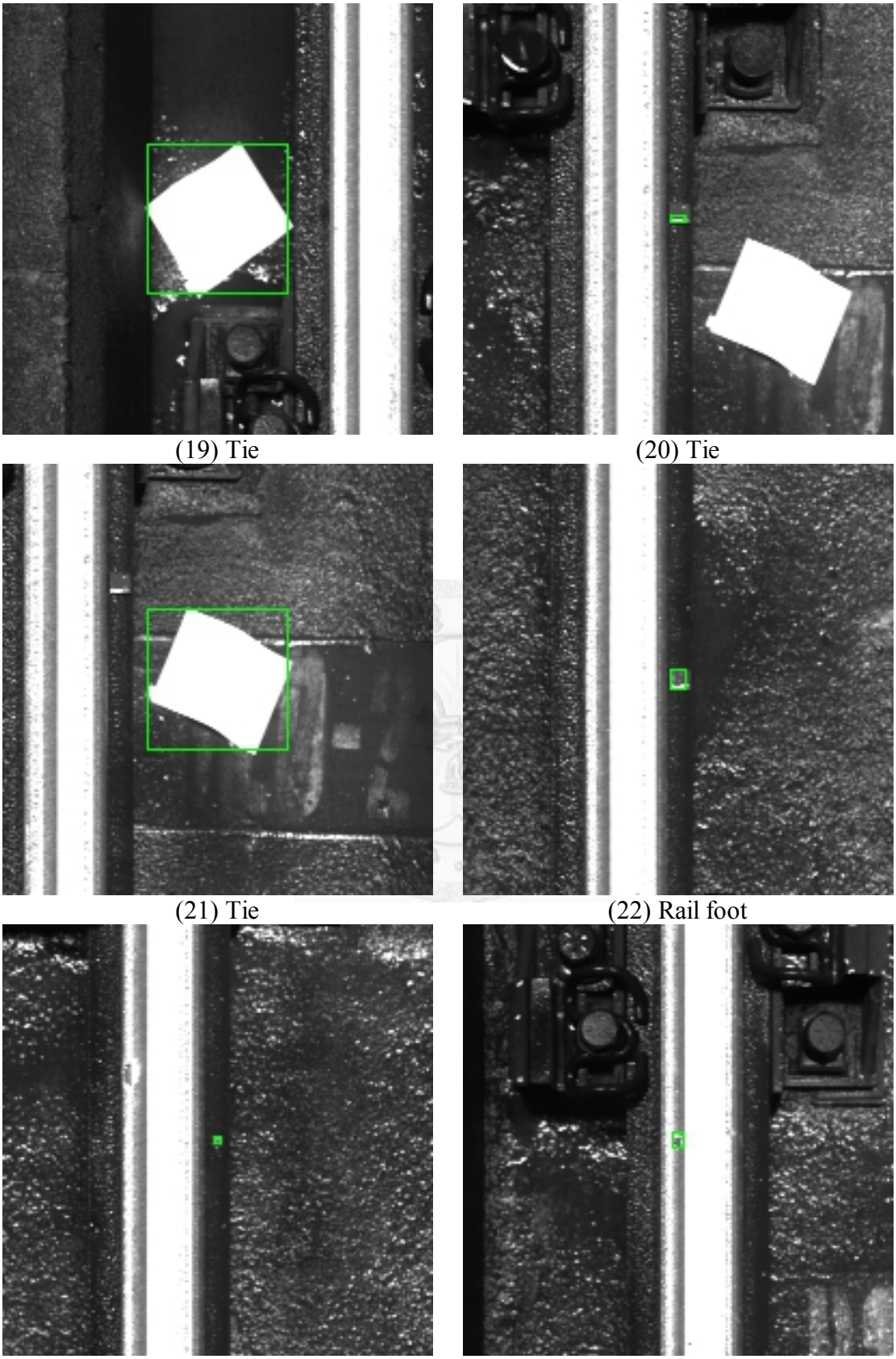


(13) Tie (14) Tie

(15) Tie (16) Tie

(17) Tie (18) Floor

Figure 4.46 Inspected defects in the elevated section after rain. Down direction left rail (III).

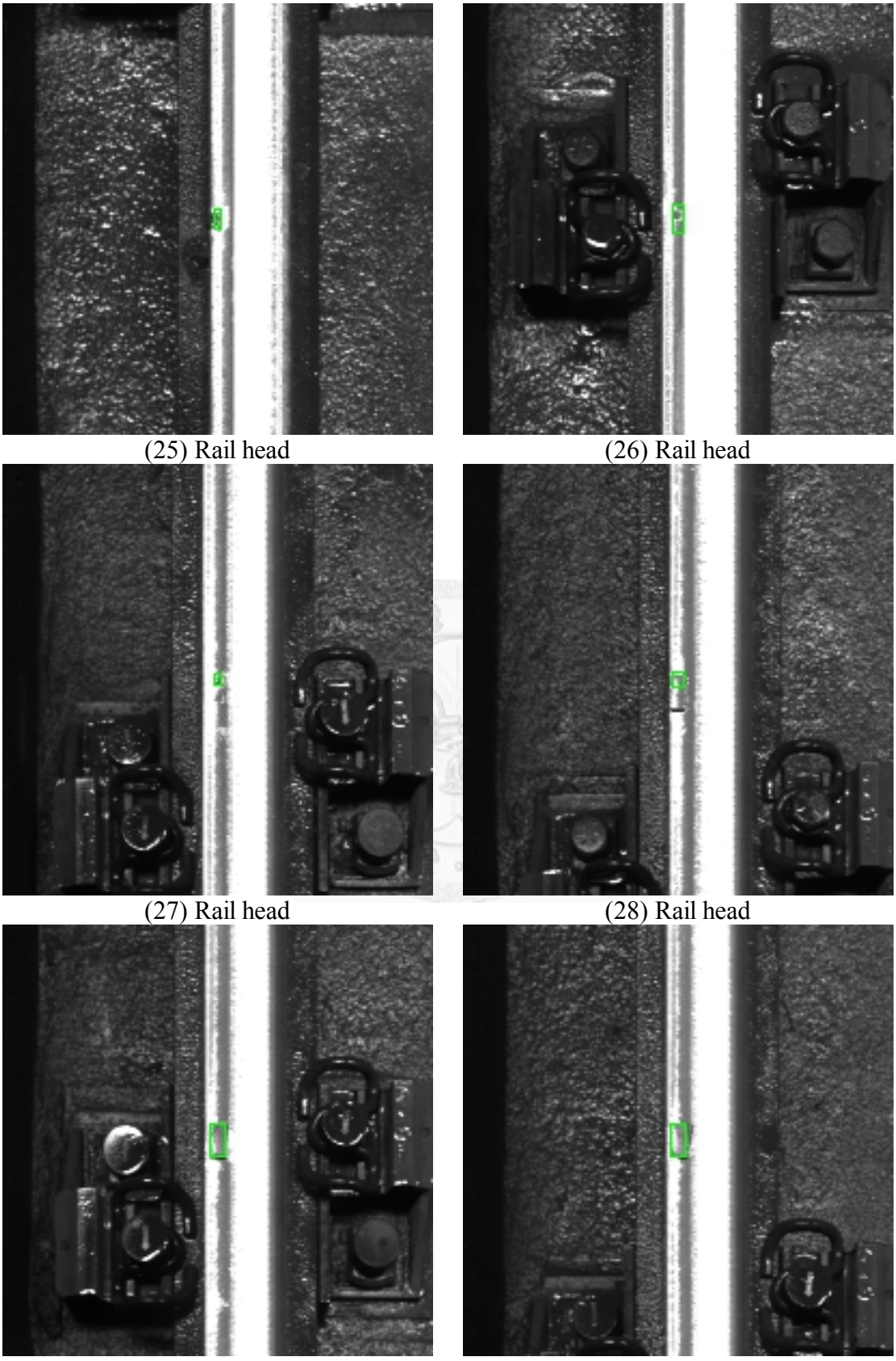


(19) Tie (20) Tie

(21) Tie (22) Rail foot

(23) Rail foot (24) Rail head

Figure 4.47 Inspected defects in the elevated section after rain. Down direction left rail (IV).

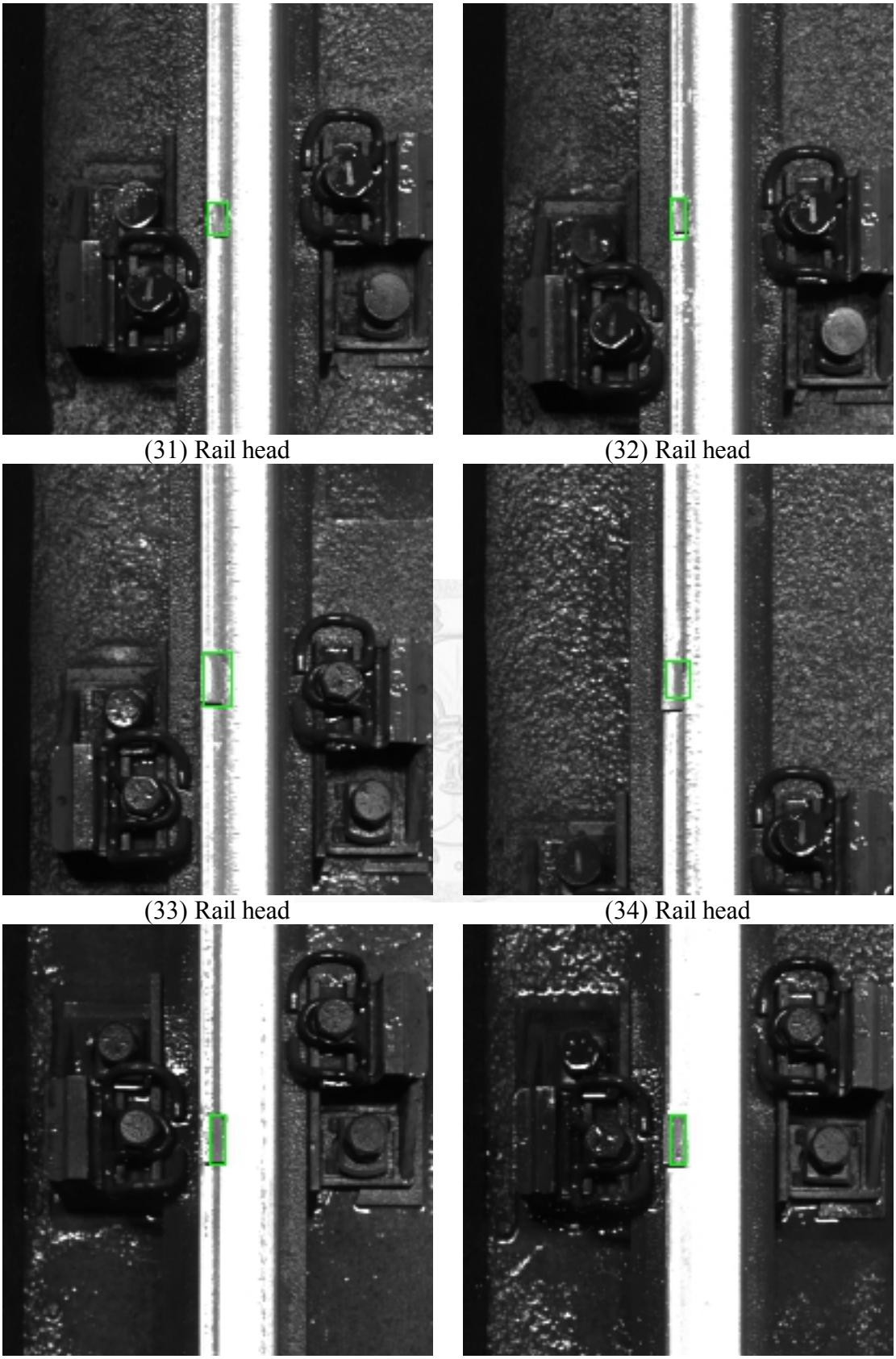


(25) Rail head (26) Rail head

(27) Rail head (28) Rail head

(29) Rail head (30) Rail head

Figure 4.48 Inspected defects in the elevated section after rain. Down direction left rail (V).

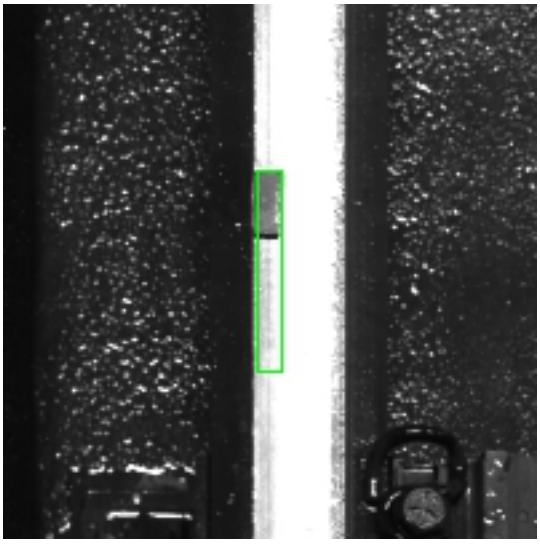


(31) Rail head (32) Rail head

(33) Rail head (34) Rail head

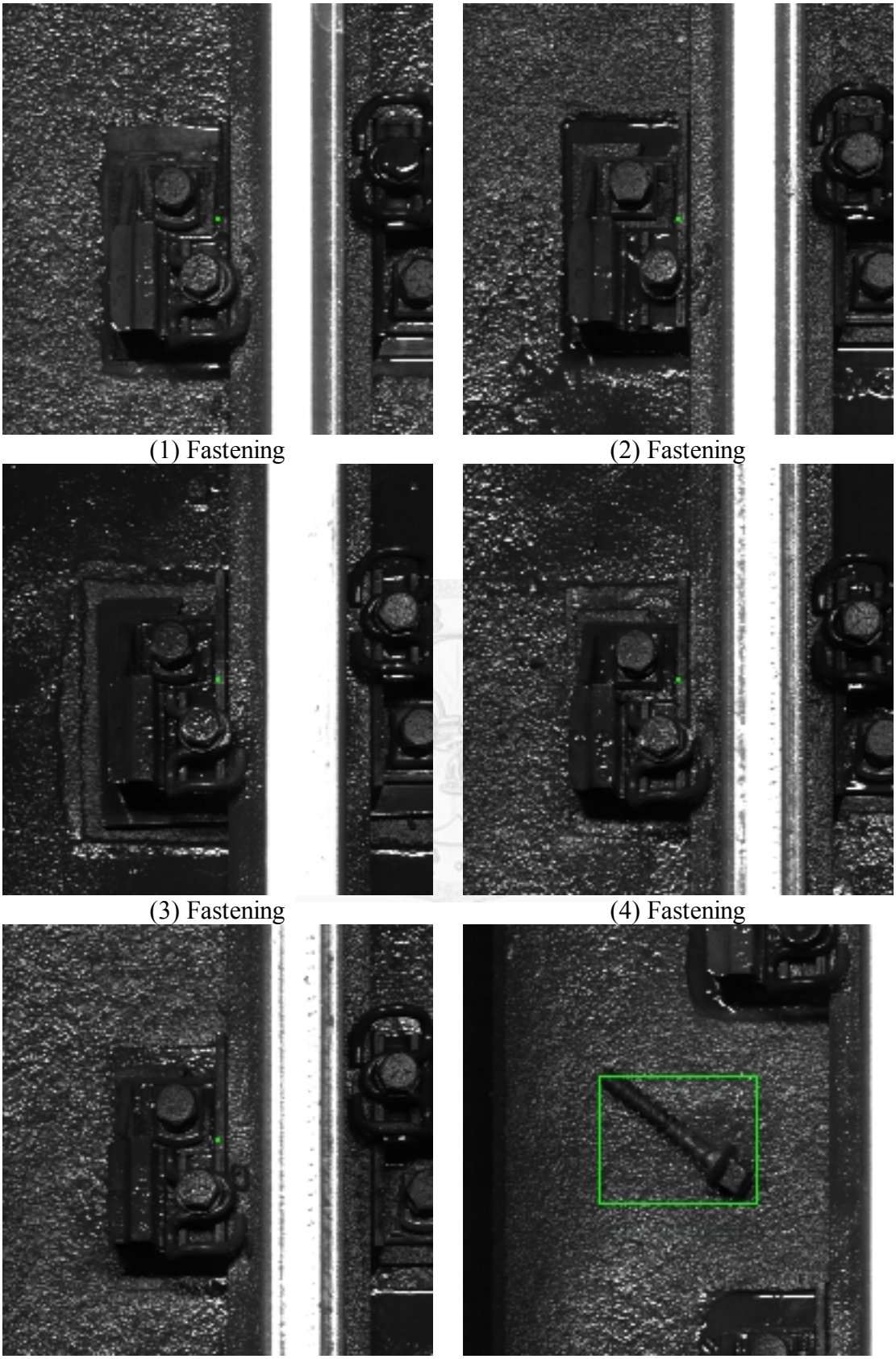
(35) Rail head (36) Rail head

Figure 4.49 Inspected defects in the elevated section after rain. Down direction left rail (VI).



(37) Rail head

Figure 4.50 Inspected defects in the elevated section after rain. Down direction left rail (VII).

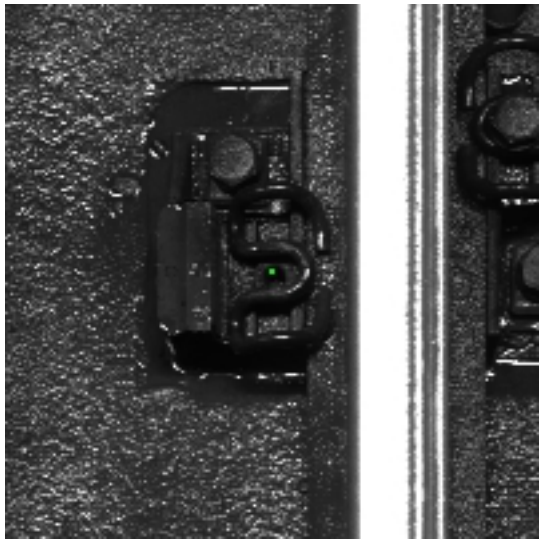


(1) Fastening (2) Fastening

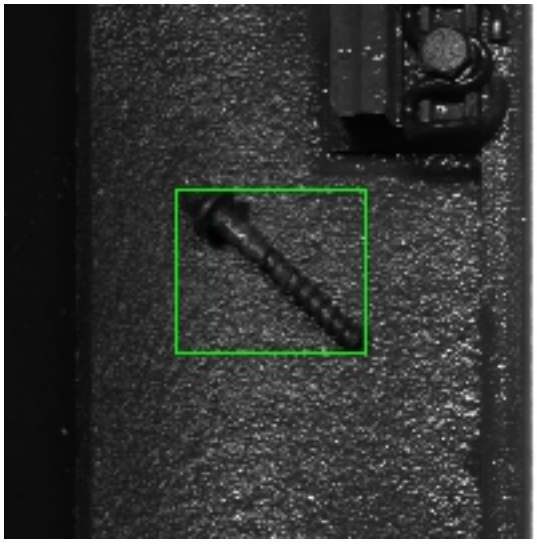
(3) Fastening (4) Fastening

(5) Fastening (6) Tie

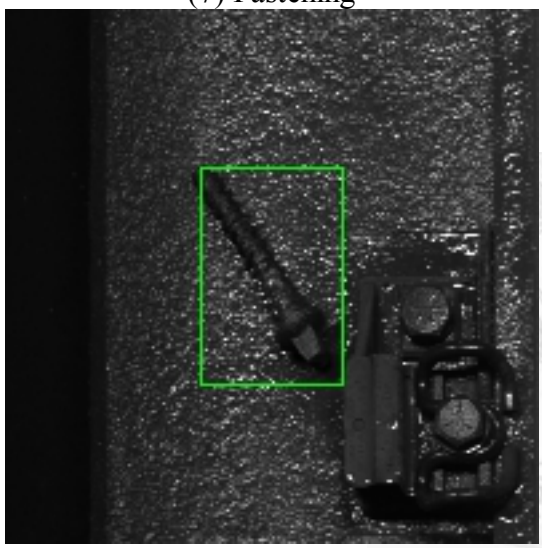
Figure 4.51 Inspected defects in the elevated section after rain. Down direction right rail (I).



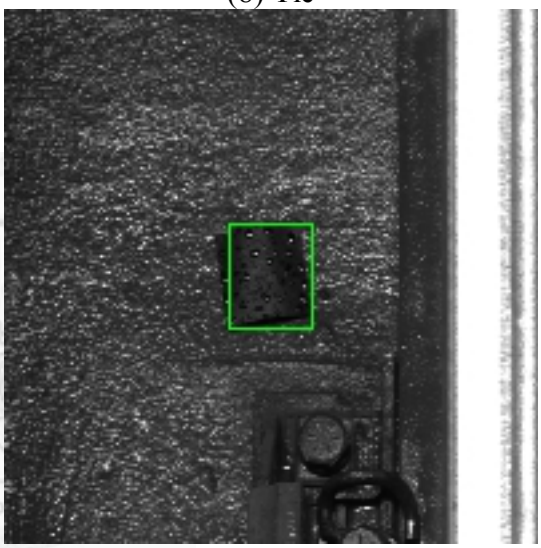
(7) Fastening



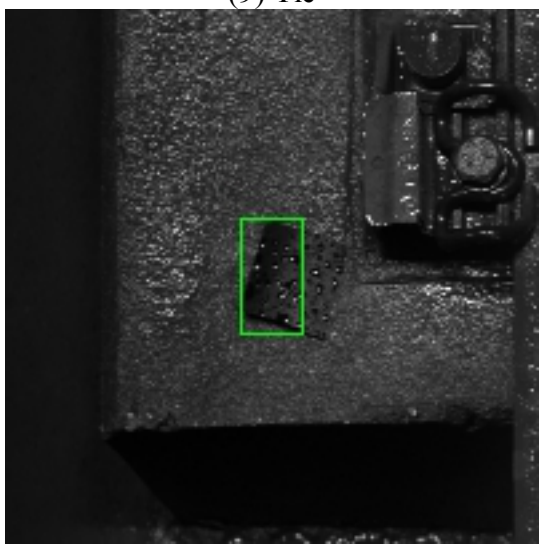
(8) Tie



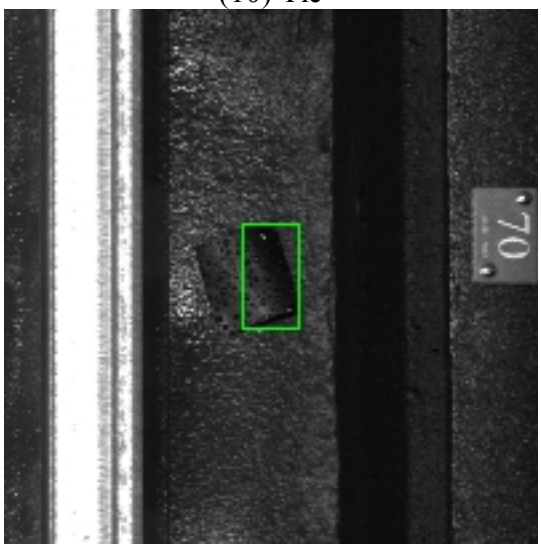
(9) Tie



(10) Tie

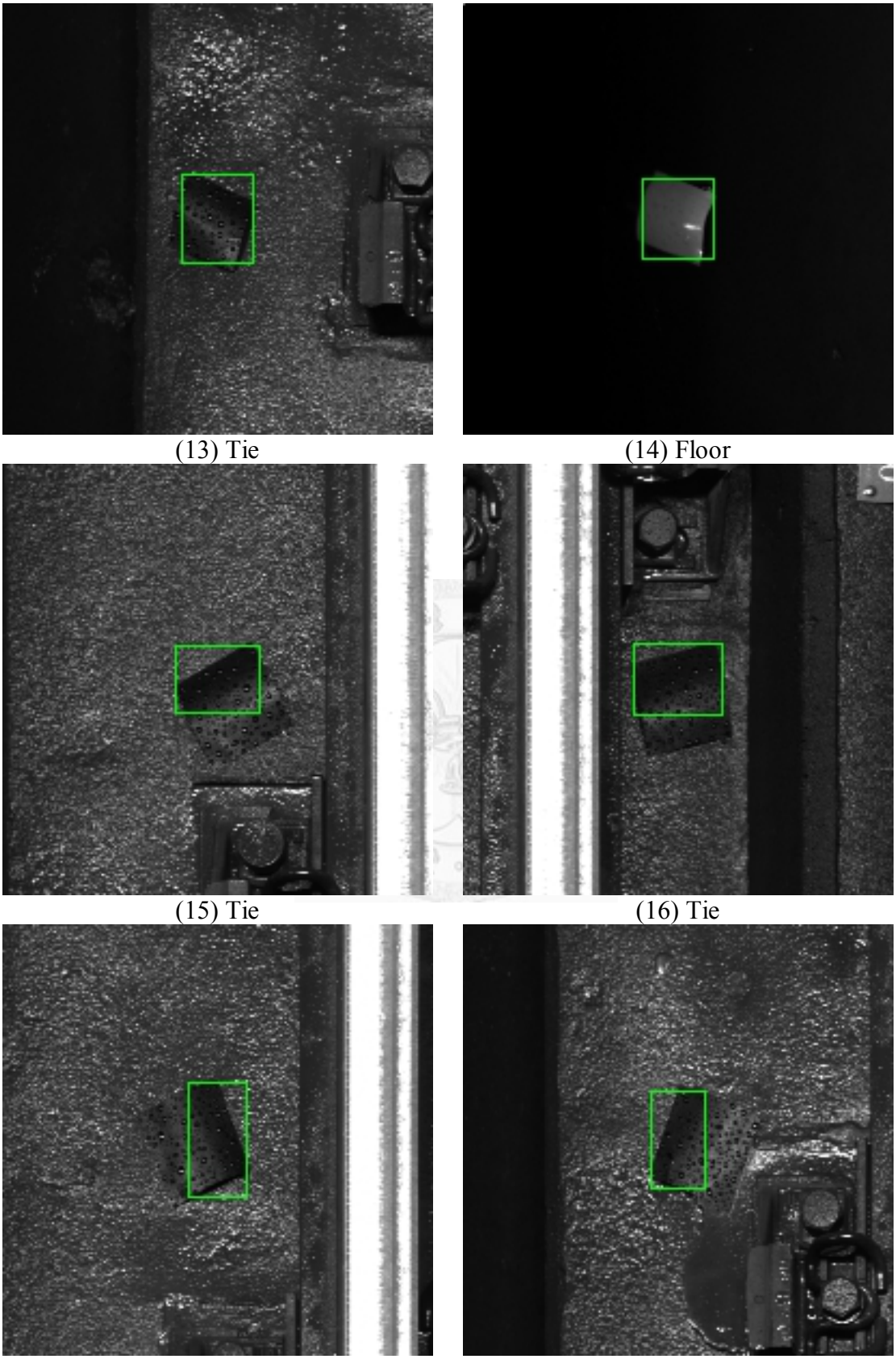


(11) Tie



(12) Tie

Figure 4.52 Inspected defects in the elevated section after rain. Down direction right rail (II).

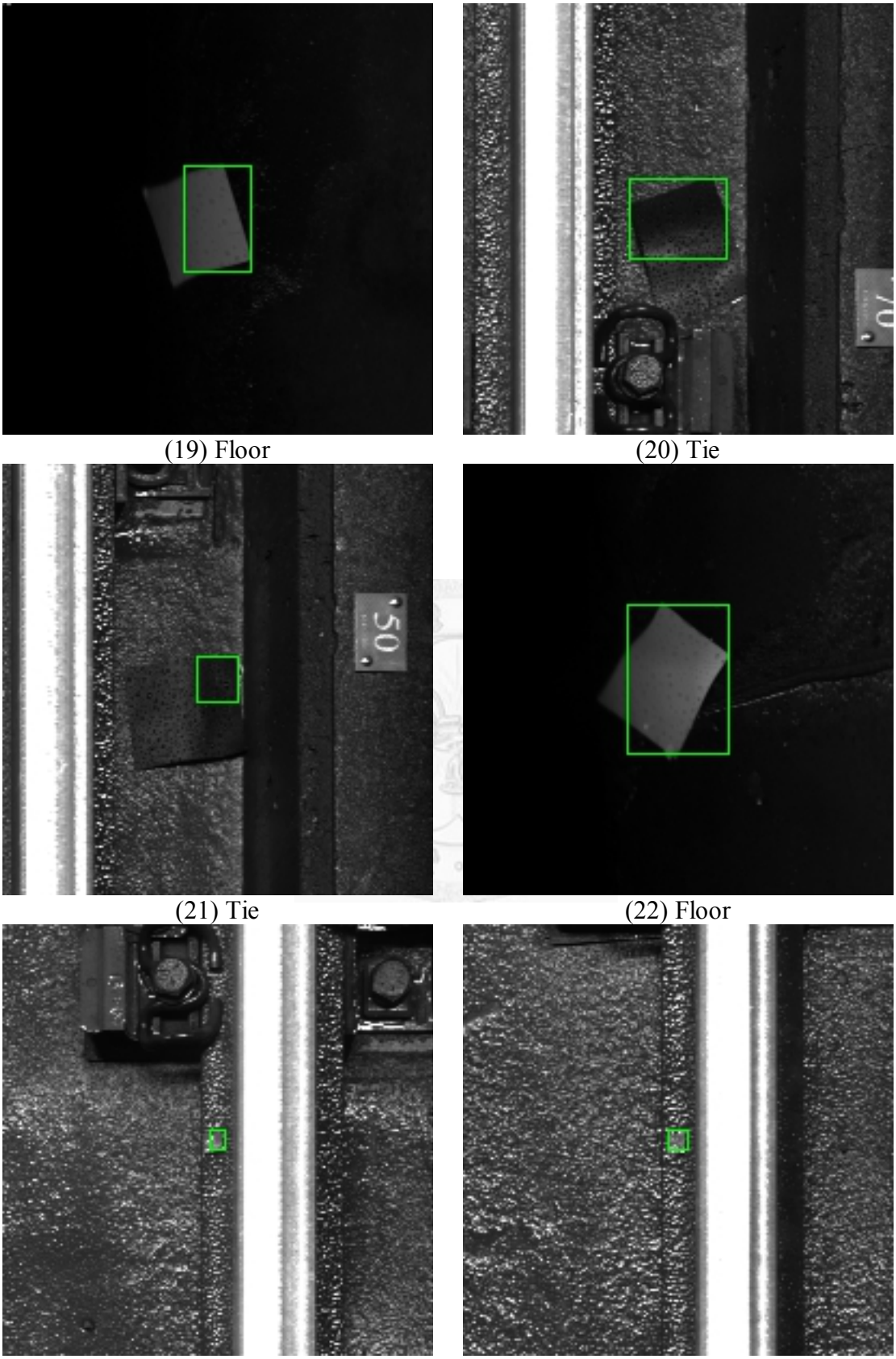


(13) Tie (14) Floor

(15) Tie (16) Tie

(17) Tie (18) Tie

Figure 4.53 Inspected defects in the elevated section after rain. Down direction right rail (III).

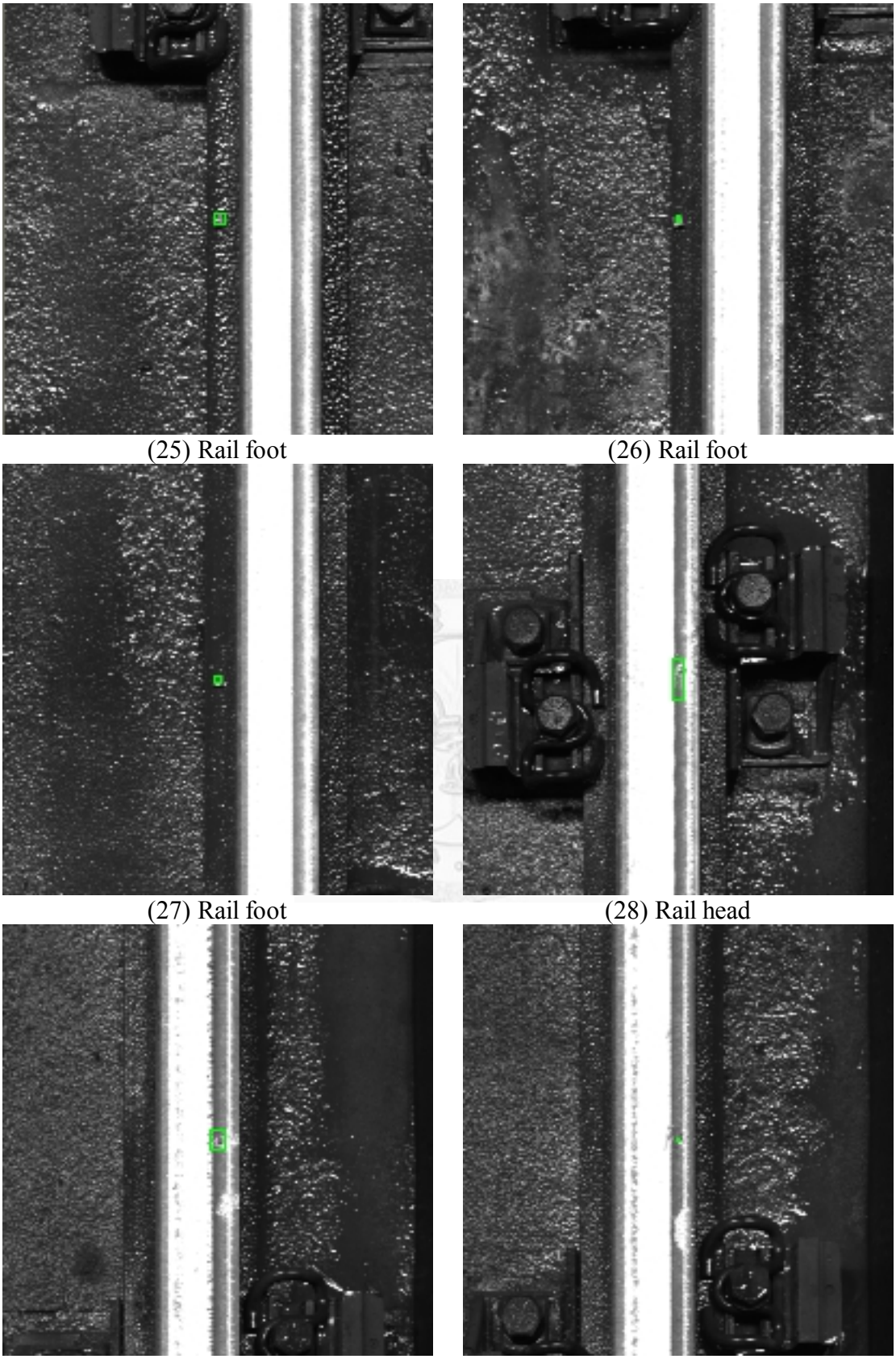


(19) Floor (20) Tie

(21) Tie (22) Floor

(23) Rail foot (24) Rail foot

Figure 4.54 Inspected defects in the elevated section after rain. Down direction right rail (IV).

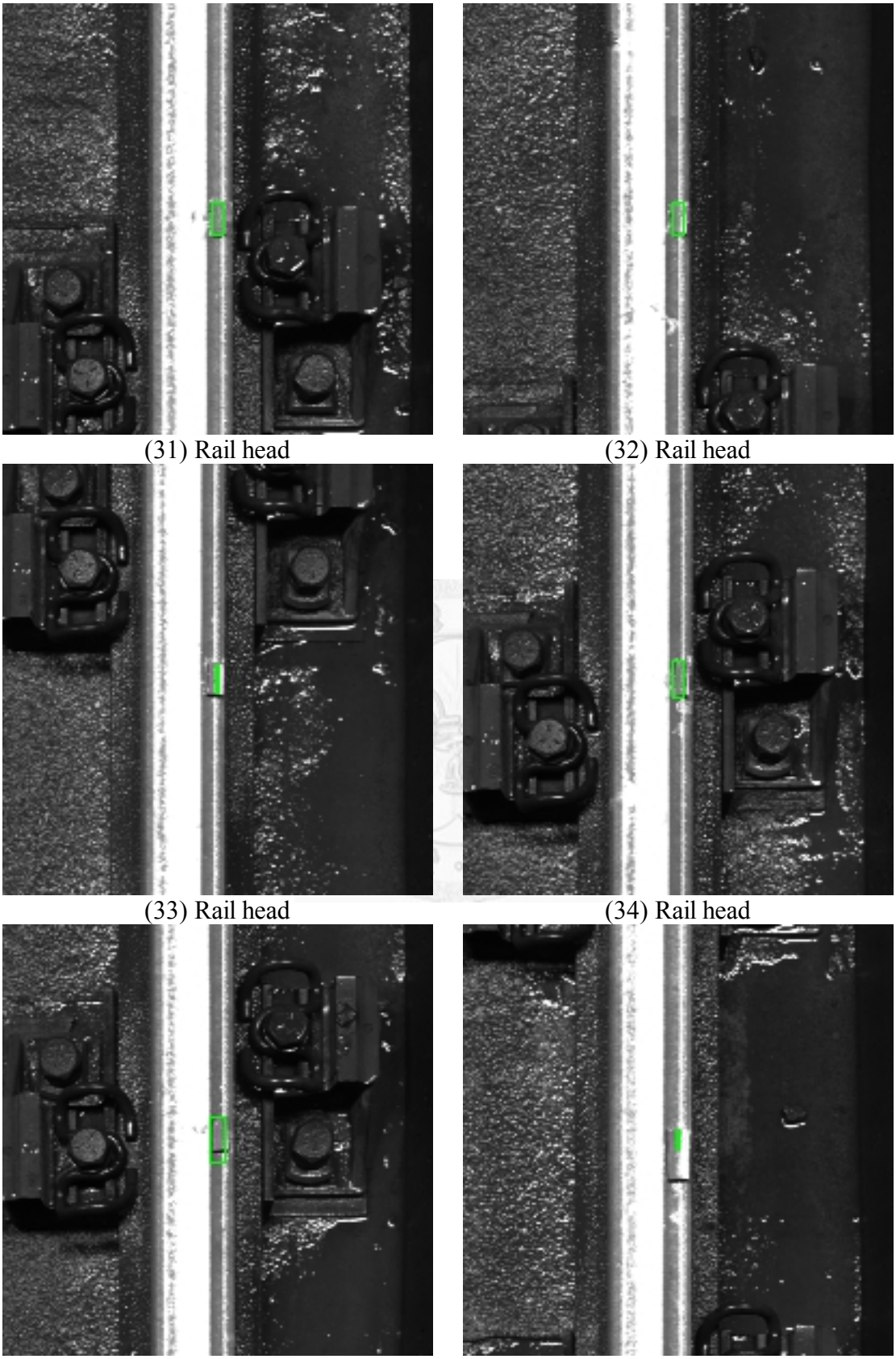


(25) Rail foot (26) Rail foot

(27) Rail foot (28) Rail head

(29) Rail head (30) Rail head

Figure 4.55 Inspected defects in the elevated section after rain. Down direction right rail (V).

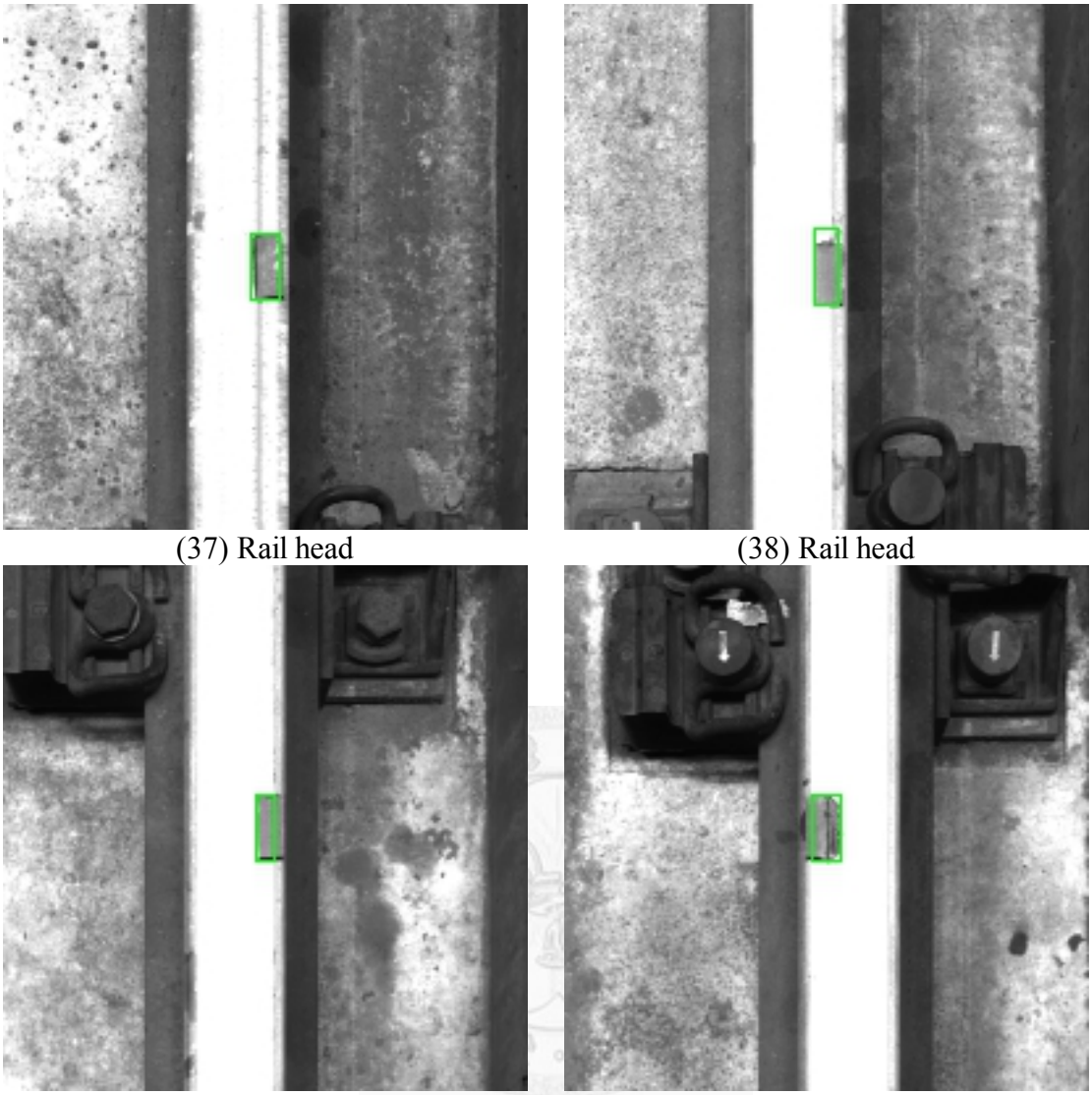


(31) Rail head (32) Rail head

(33) Rail head (34) Rail head

(35) Rail head (36) Rail head

Figure 4.56 Inspected defects in the elevated section after rain. Down direction right rail (VI).



(37) Rail head (38) Rail head

(39) Rail head (40) Rail head

Figure 4.57 Inspected defects in the elevated section after rain. Down direction right rail (VII).

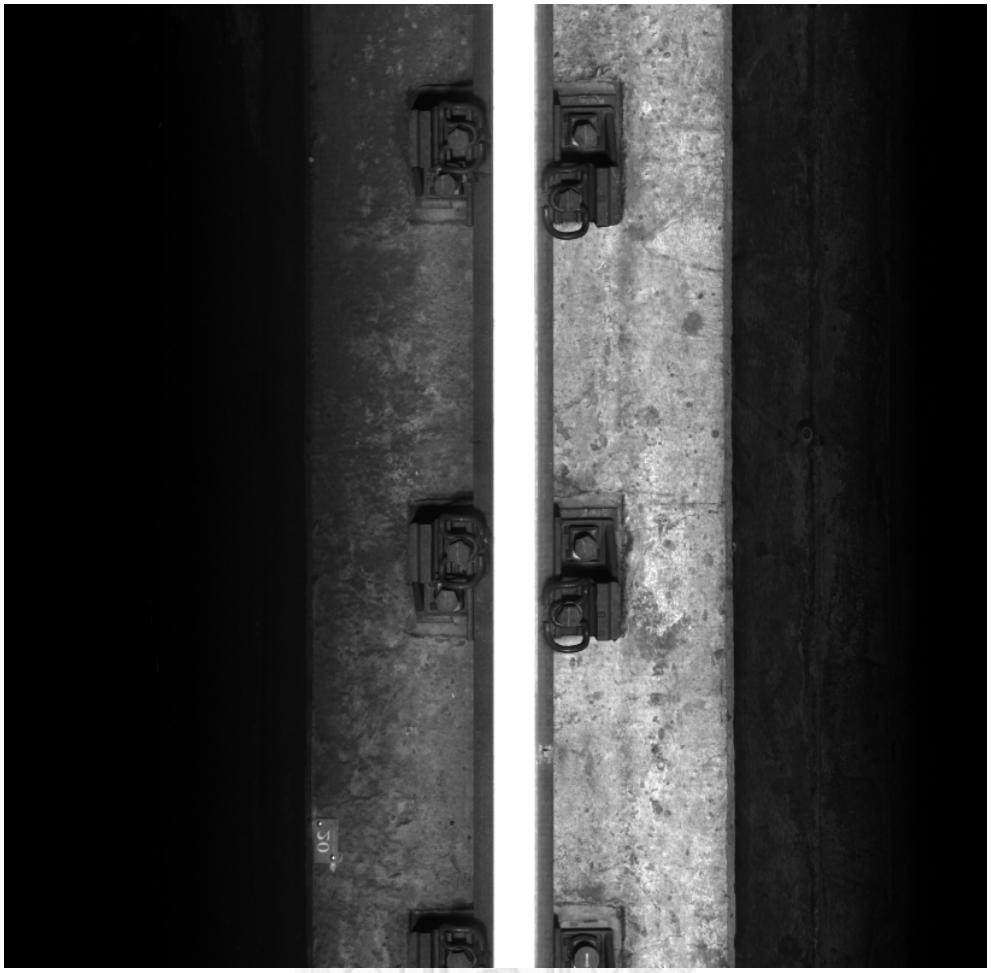


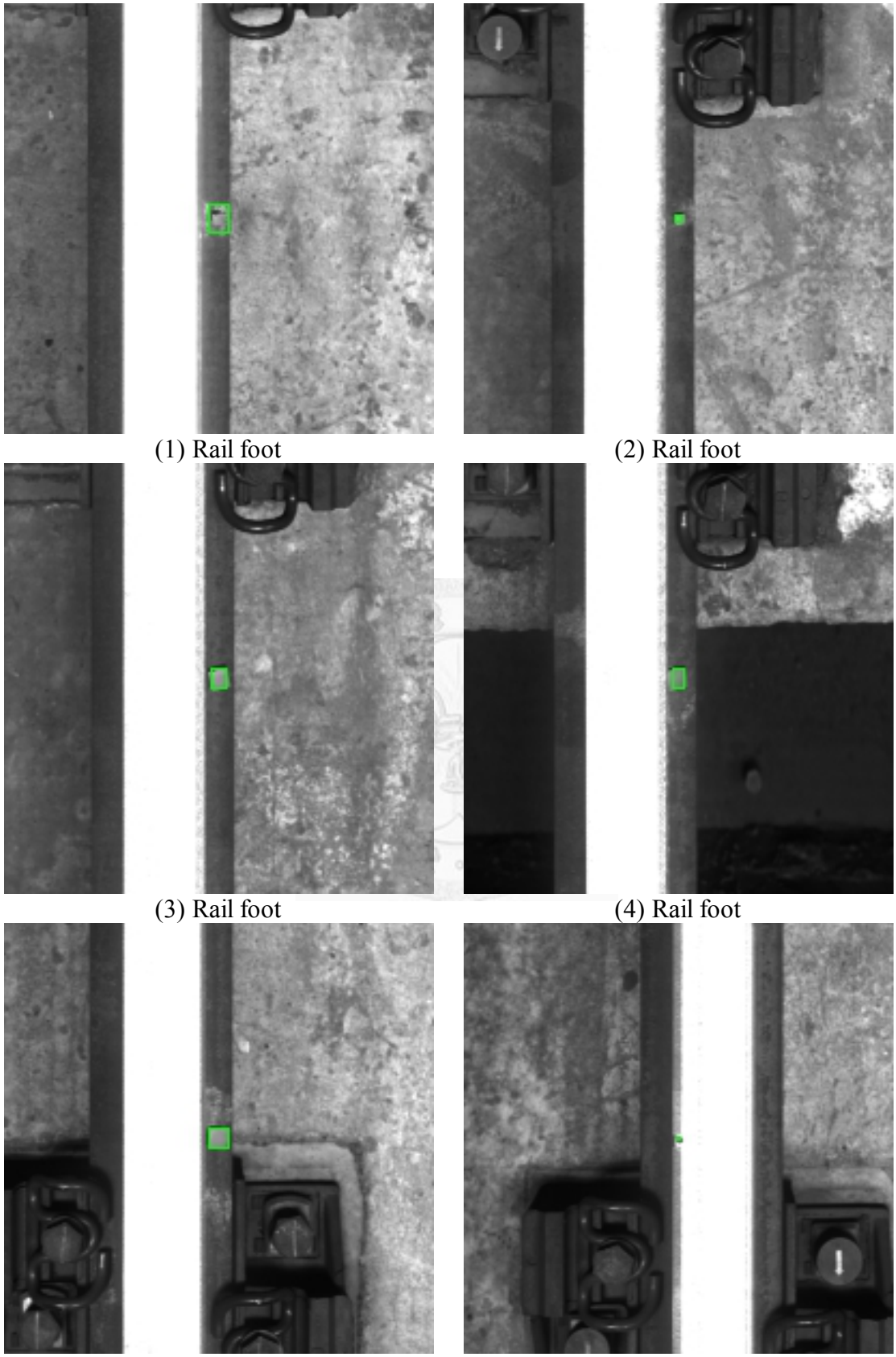
Figure 4.58 The sample page of the underground section.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 51 | 42 | 82.35% |
| Right Rail | 43 | 31 | 72.09% |
| Total | 94 | 73 | 77.66% |

Figure 4.59 The inspection statistics for the underground section up direction.

| | Number of Artificial Defects | Number of Inspected Defects | Inspection Rate |
|---|---|---|---|
| Left Rail | 50 | 43 | 86.00% |
| Right Rail | 50 | 44 | 88.00% |
| Total | 100 | 87 | 87.00% |

Figure 4.60 The inspection statistics for the Underground section down direction.

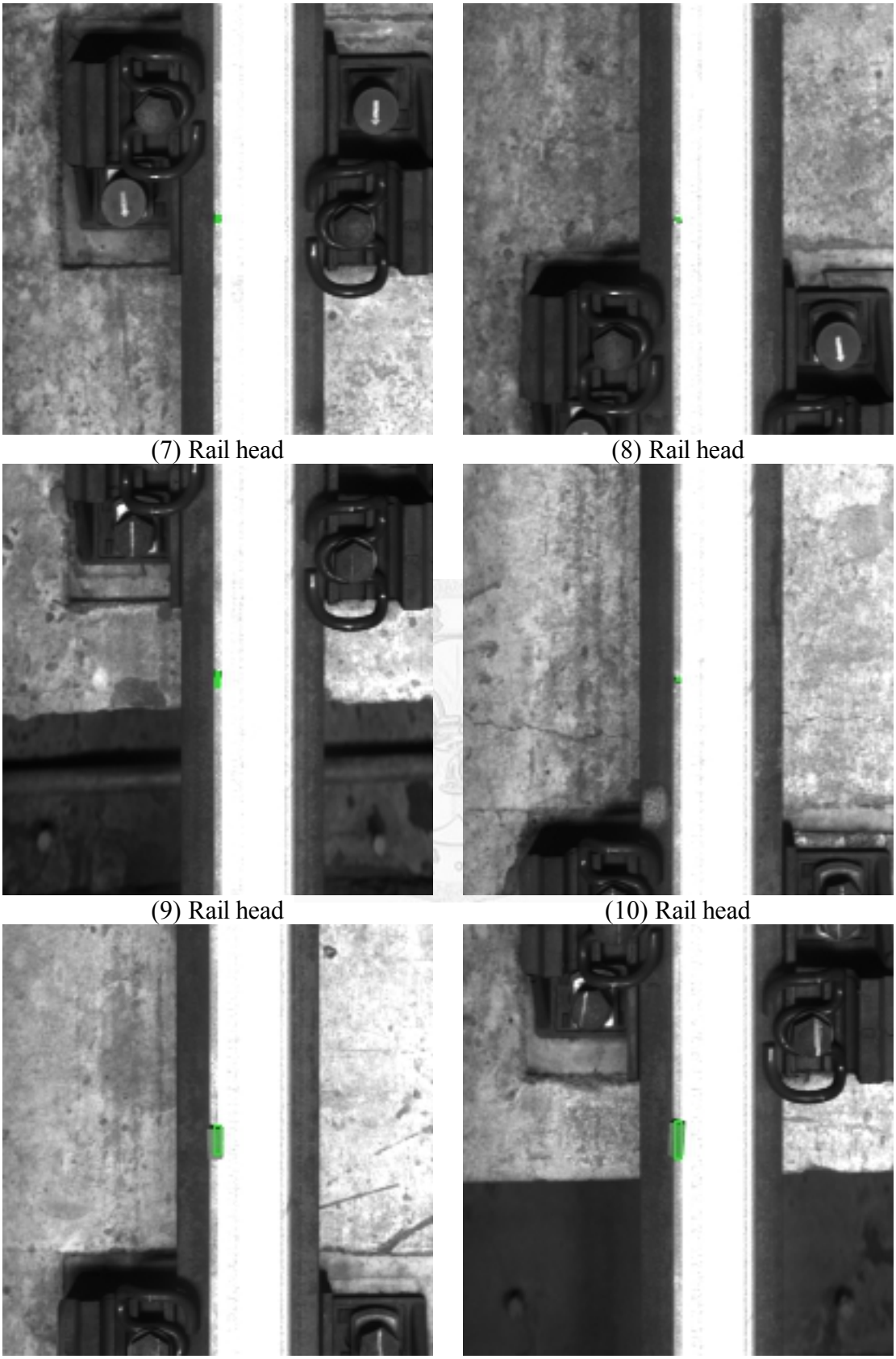


(1) Rail foot (2) Rail foot

(3) Rail foot (4) Rail foot

(5) Rail foot (6) Rail head

Figure 4.61 Inspected defects in the underground section. Up direction left rail (I).

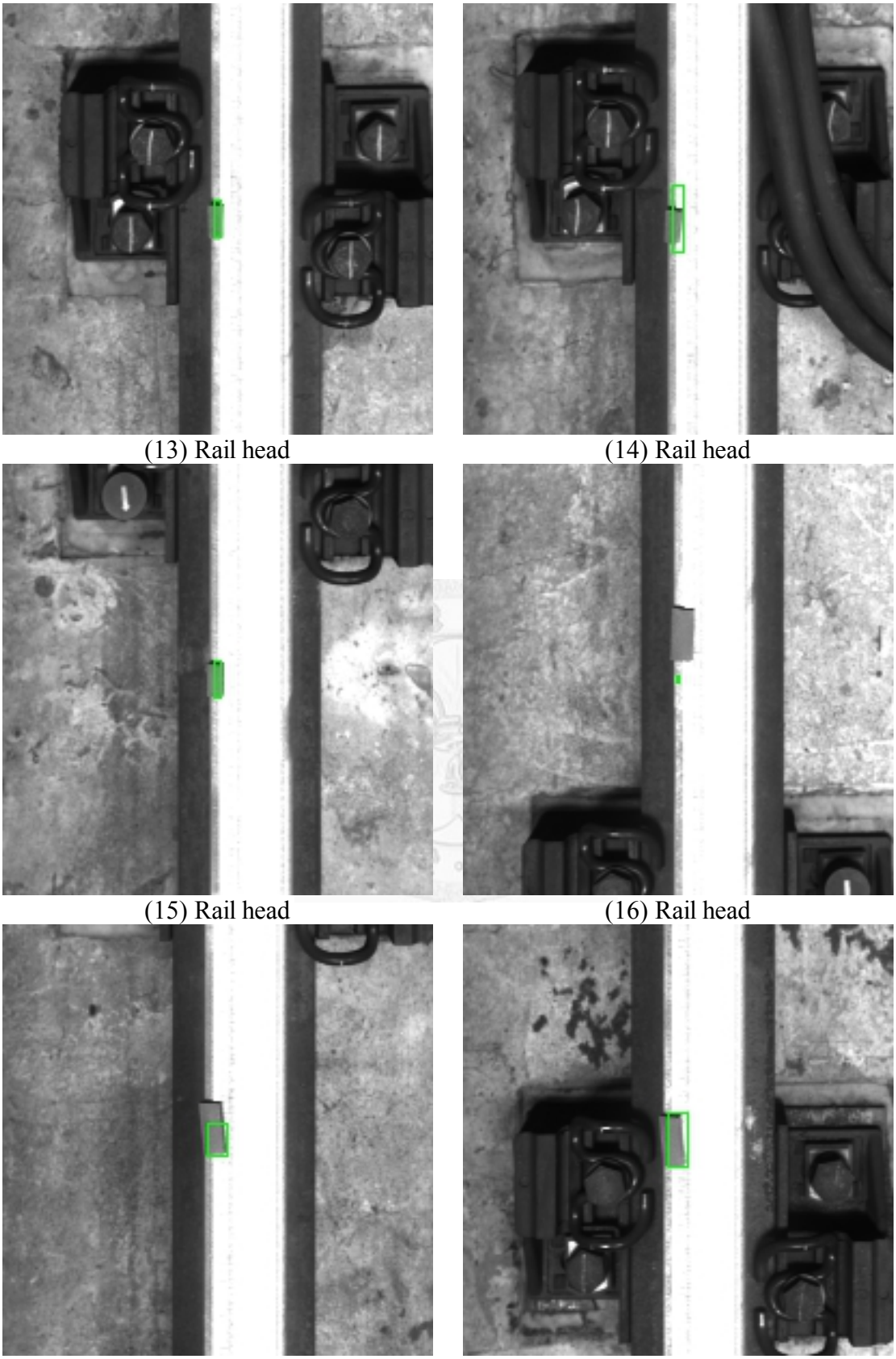


(7) Rail head (8) Rail head

(9) Rail head (10) Rail head

(11) Rail head (12) Rail head

Figure 4.62 Inspected defects in the underground section. Up direction left rail (II).

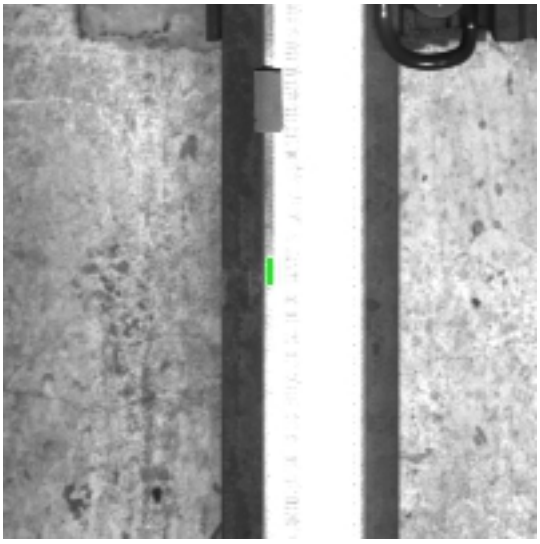


(13) Rail head (14) Rail head

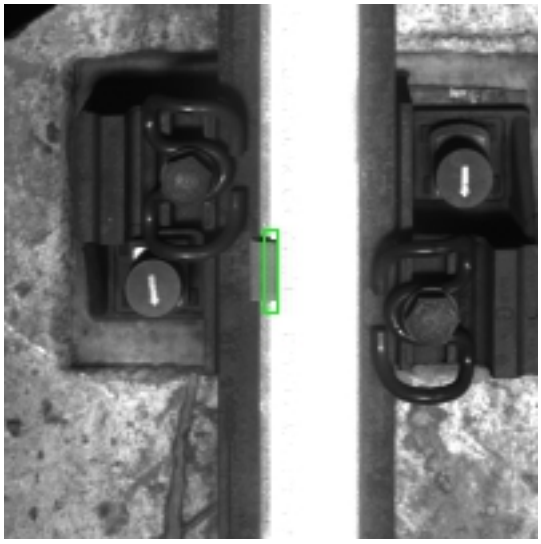
(15) Rail head (16) Rail head

(17) Rail head (18) Rail head

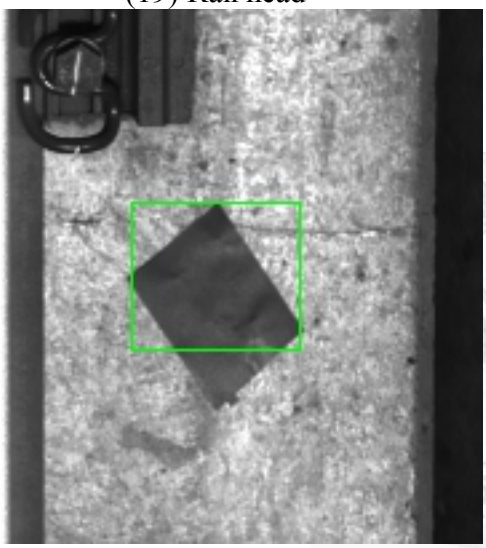
Figure 4.63 Inspected defects in the underground section. Up direction left rail (III).



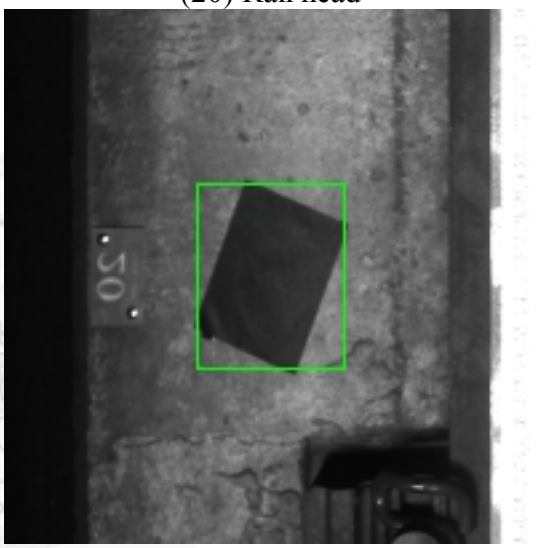
(19) Rail head



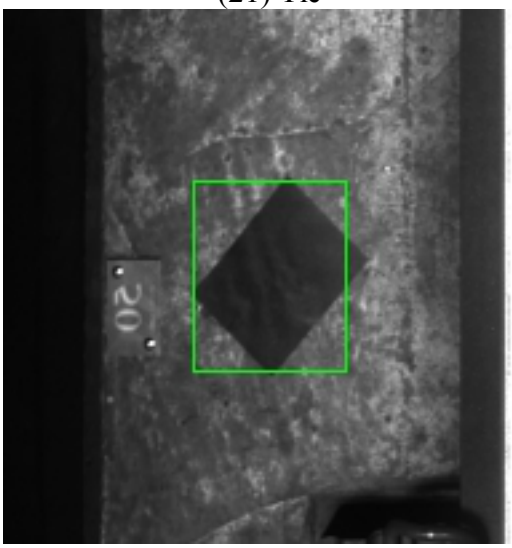
(20) Rail head



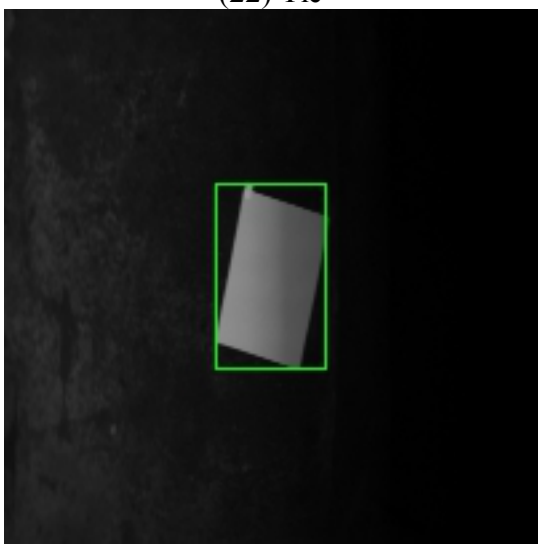
(21) Tie



(22) Tie

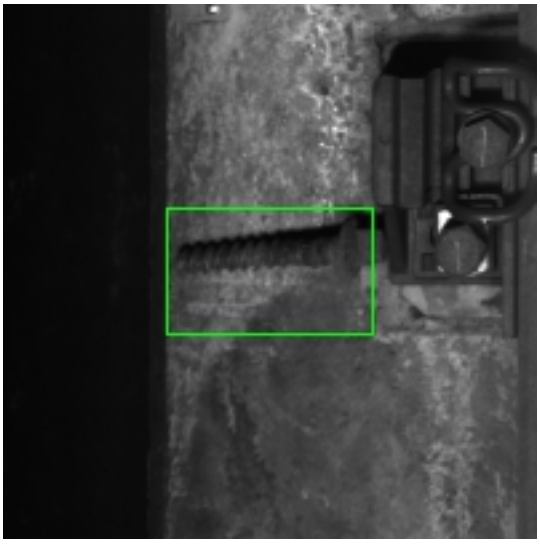


(23) Tie

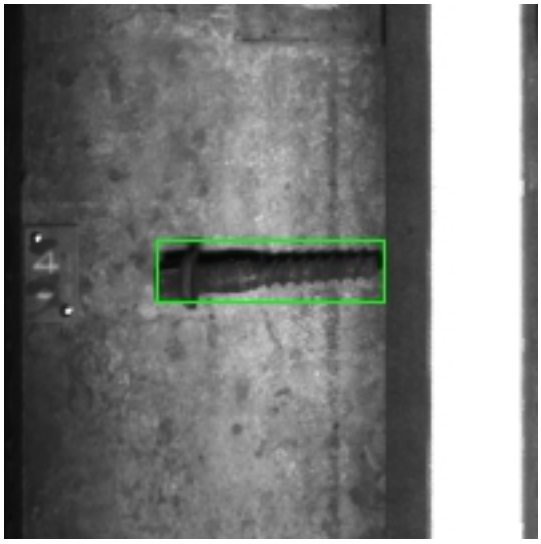


(24) Floor

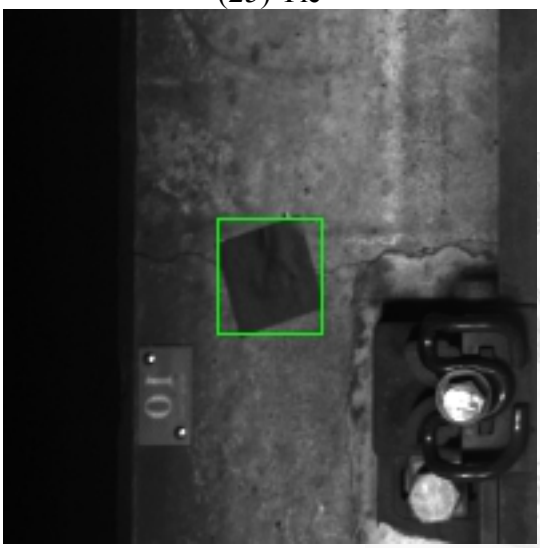
Figure 4.64 Inspected defects in the underground section. Up direction left rail (IV).



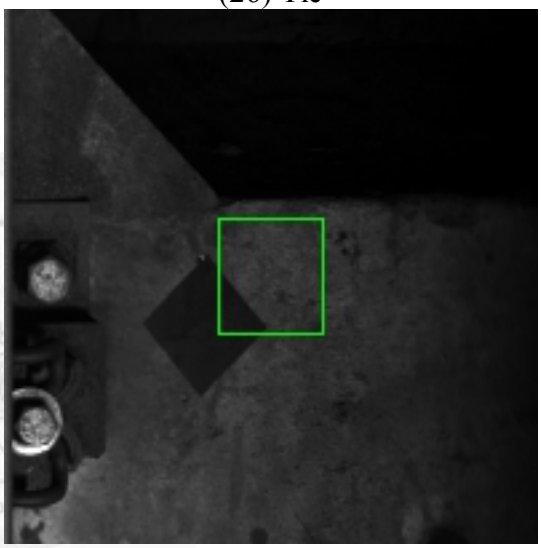
(25) Tie



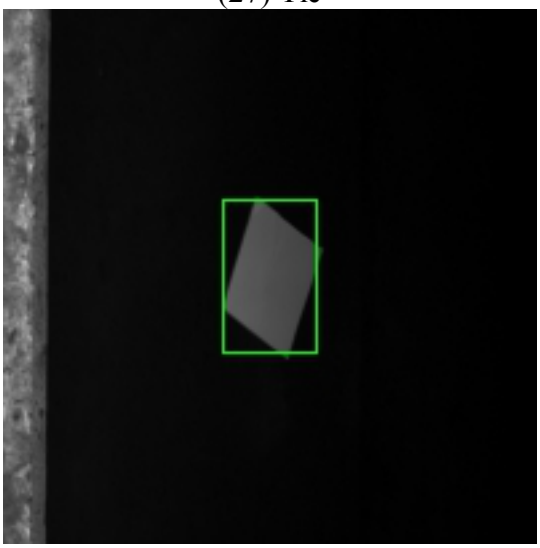
(26) Tie



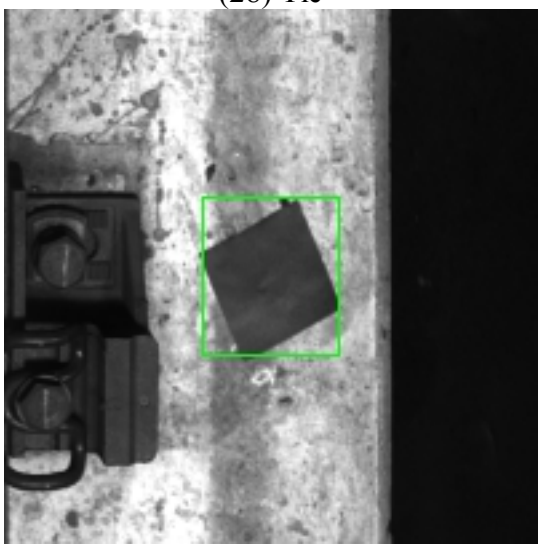
(27) Tie



(28) Tie

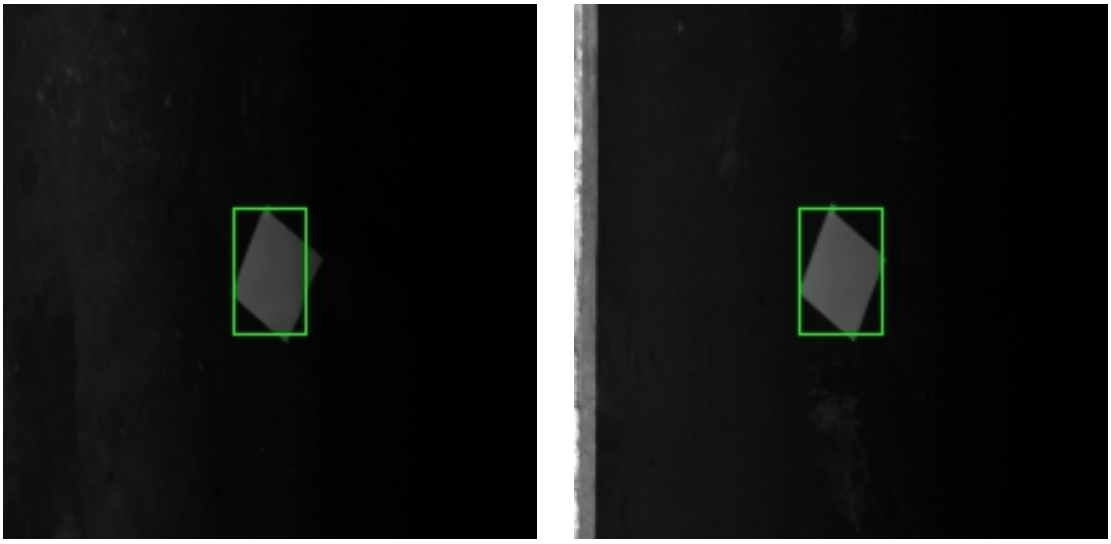


(29) Floor

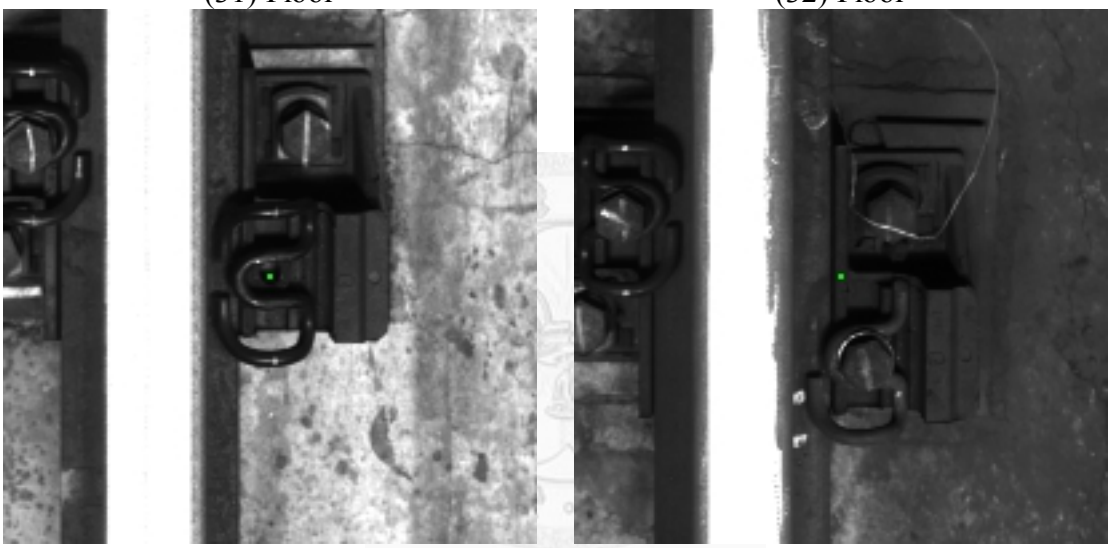


(30) Tie

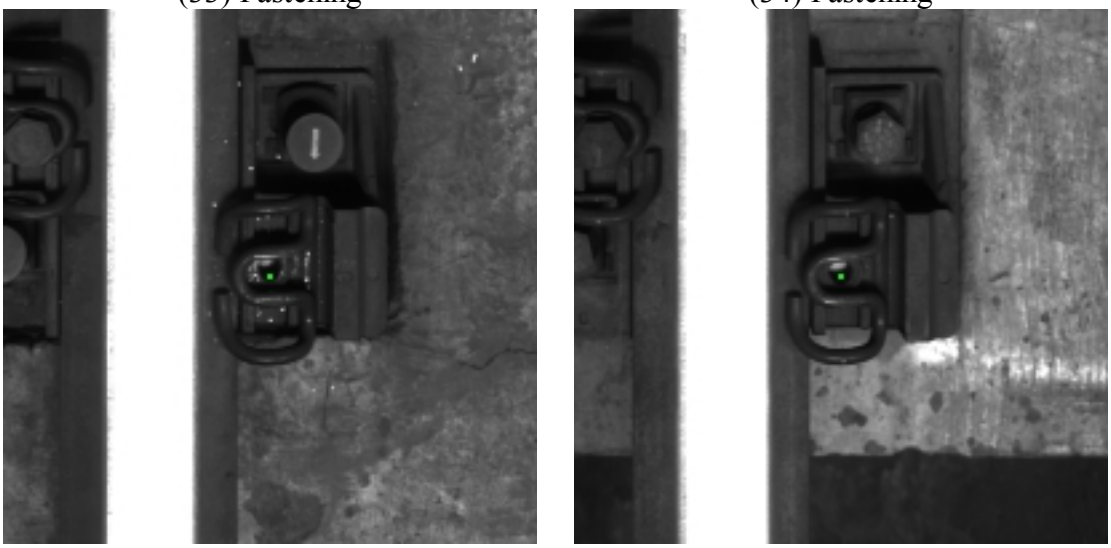
Figure 4.65 Inspected defects in the underground section. Up direction left rail (V).



(31) Floor (32) Floor

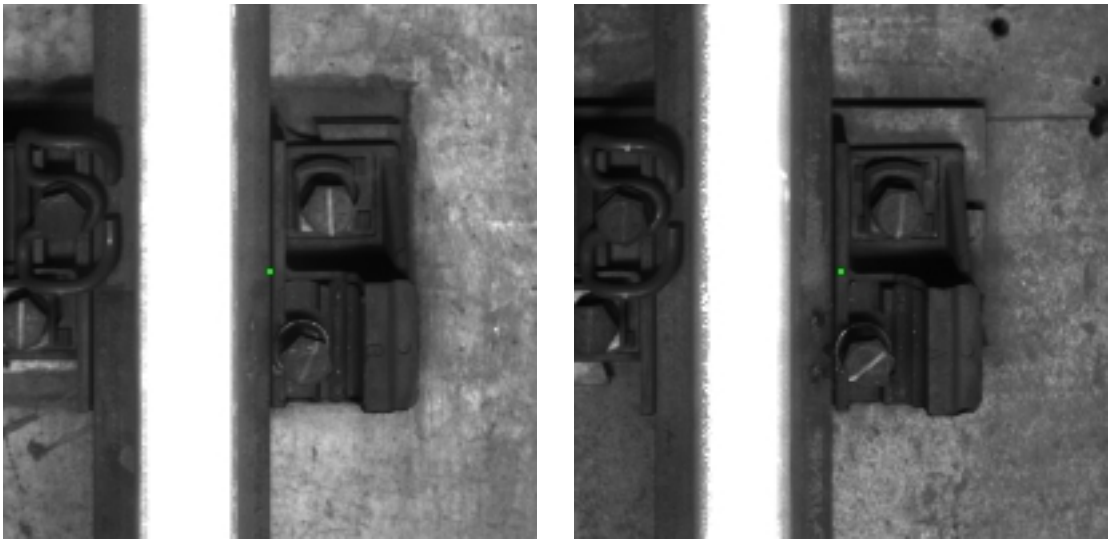


(33) Fastening (34) Fastening

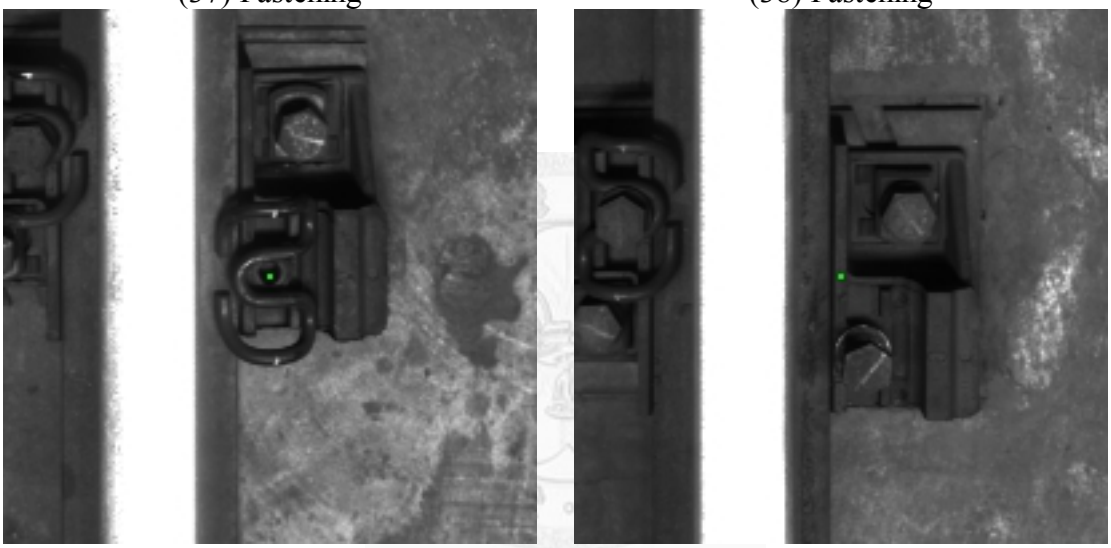


(35) Fastening (36) Fastening

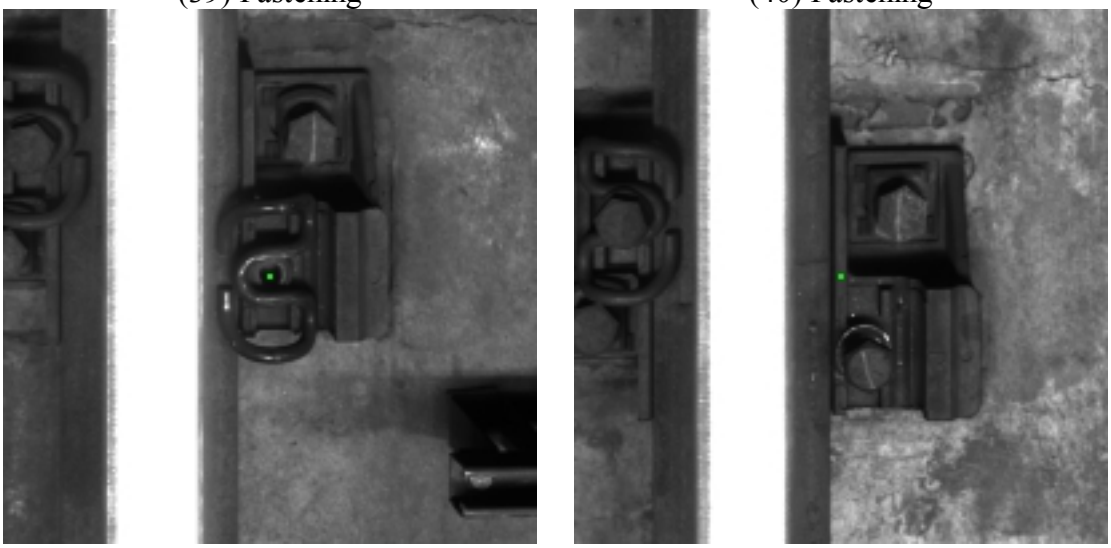
Figure 4.66 Inspected defects in the underground section. Up direction left rail (VI).



(37) Fastening (38) Fastening

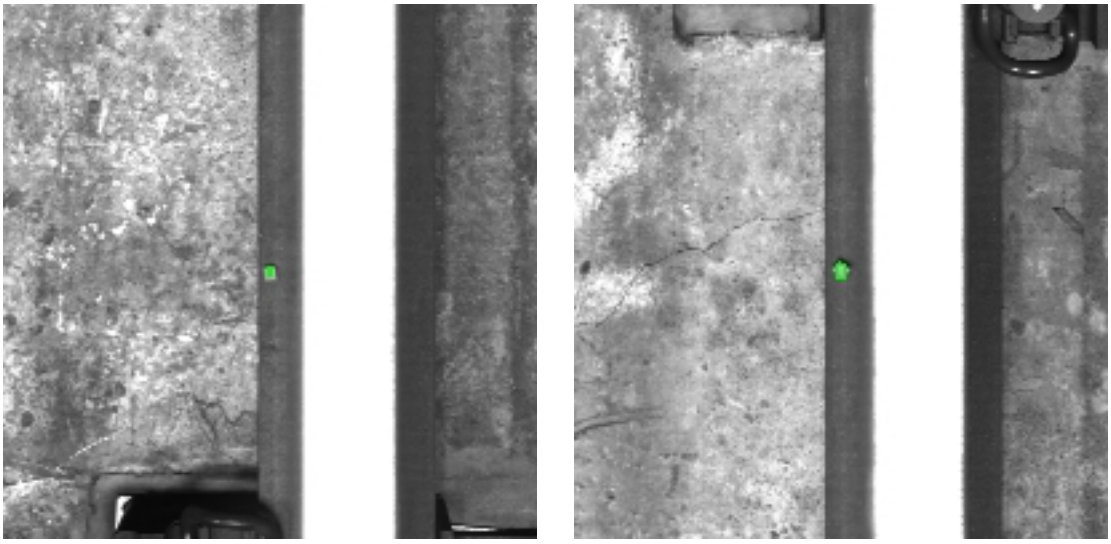


(39) Fastening (40) Fastening

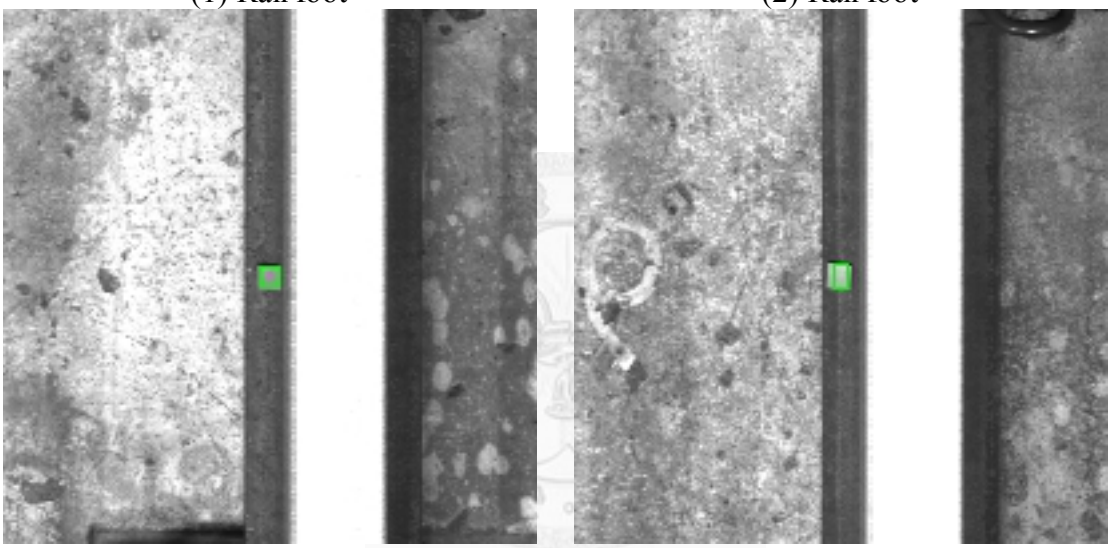


(41) Fastening (42) Fastening

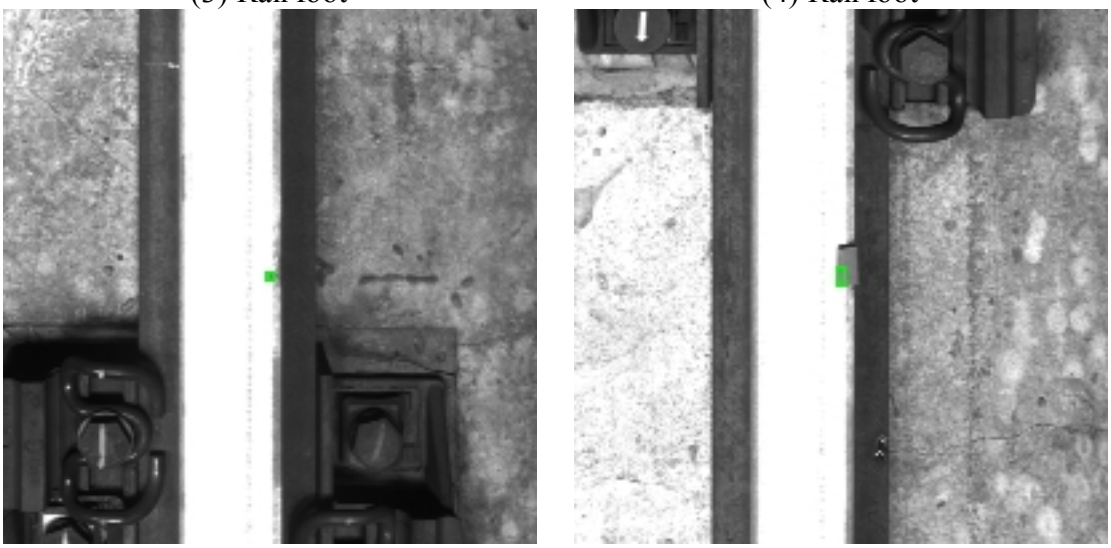
Figure 4.67 Inspected defects in the underground section. Up direction left rail (VII).



(1) Rail foot (2) Rail foot

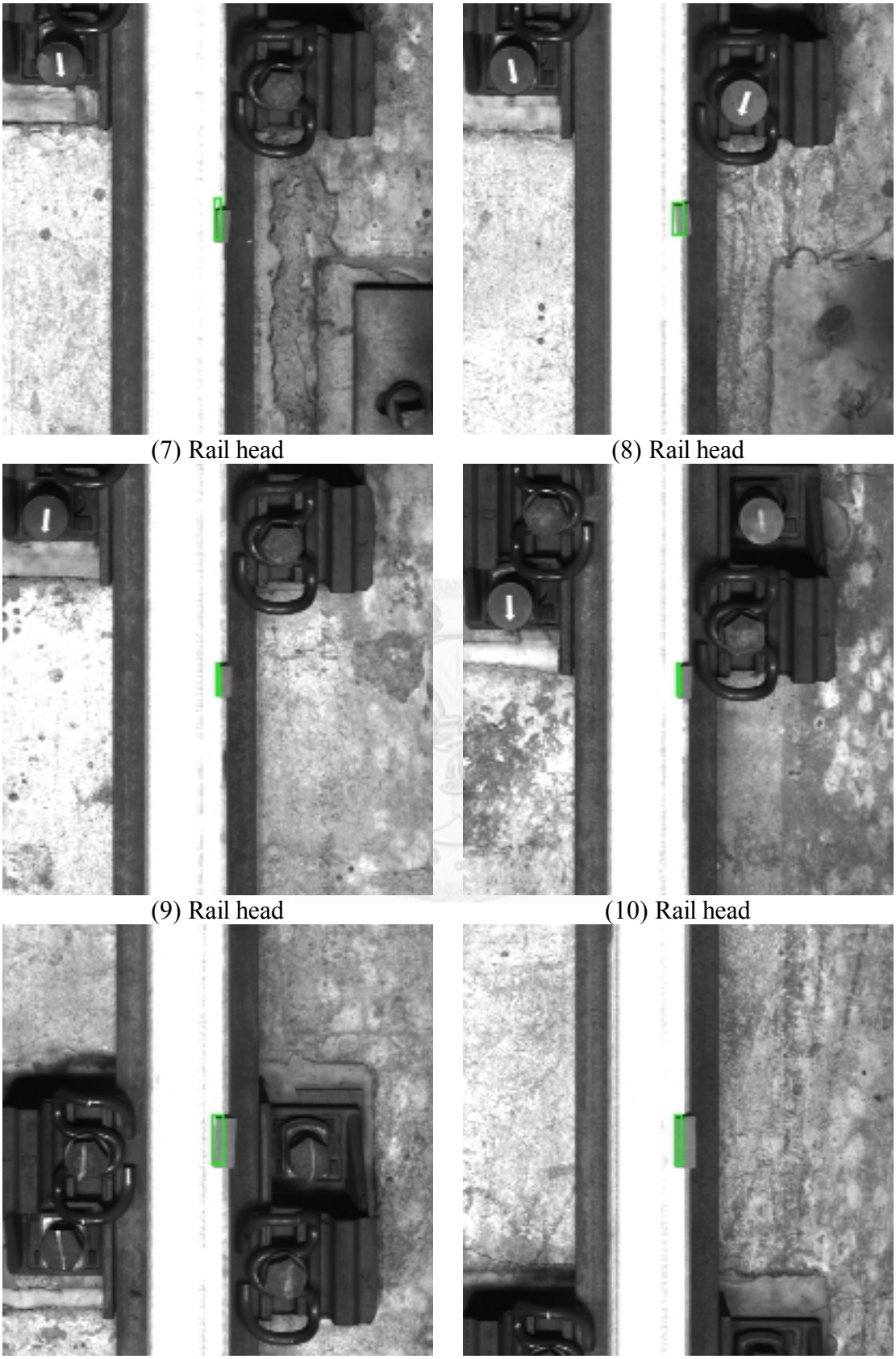


(3) Rail foot (4) Rail foot



(5) Rail head (6) Rail head

Figure 4.68 Inspected defects in the underground section. Up direction right rail (I).

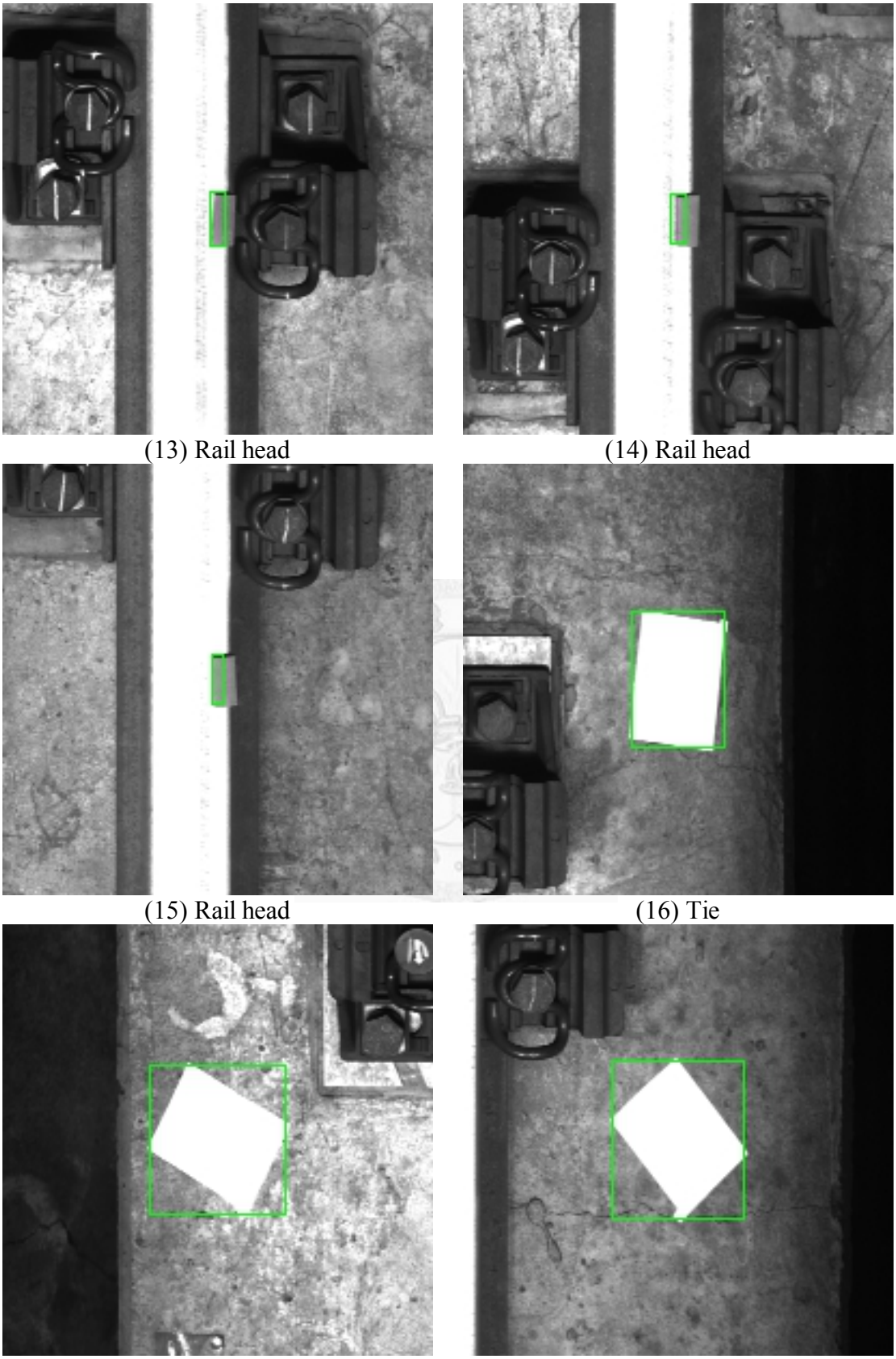


(7) Rail head (8) Rail head

(9) Rail head (10) Rail head

(11) Rail head (12) Rail head

Figure 4.69 Inspected defects in the underground section. Up direction right rail (II).

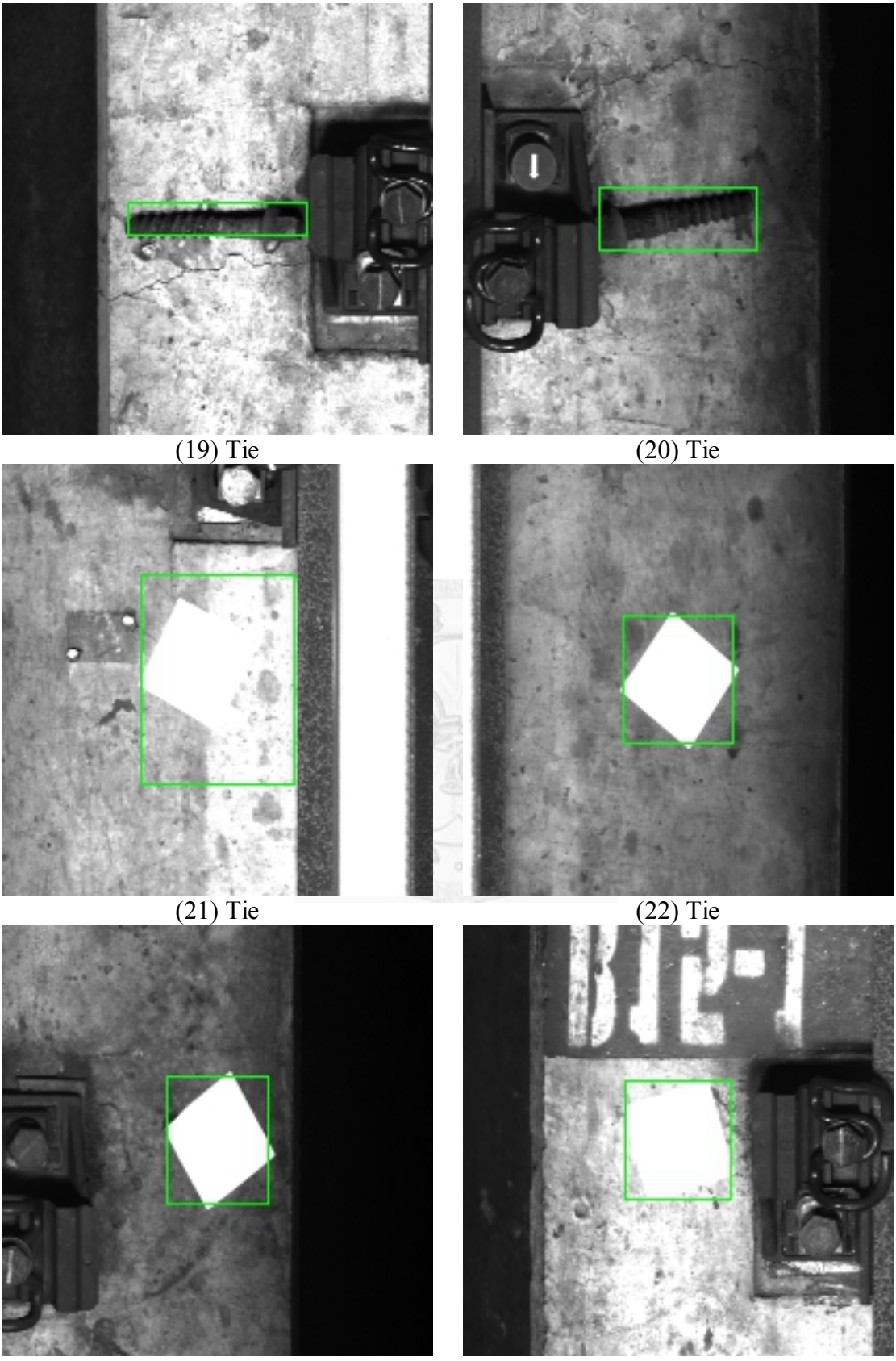


(13) Rail head (14) Rail head

(15) Rail head (16) Tie

(17) Tie (18) Tie

Figure 4.70 Inspected defects in the underground section. Up direction right rail (III).

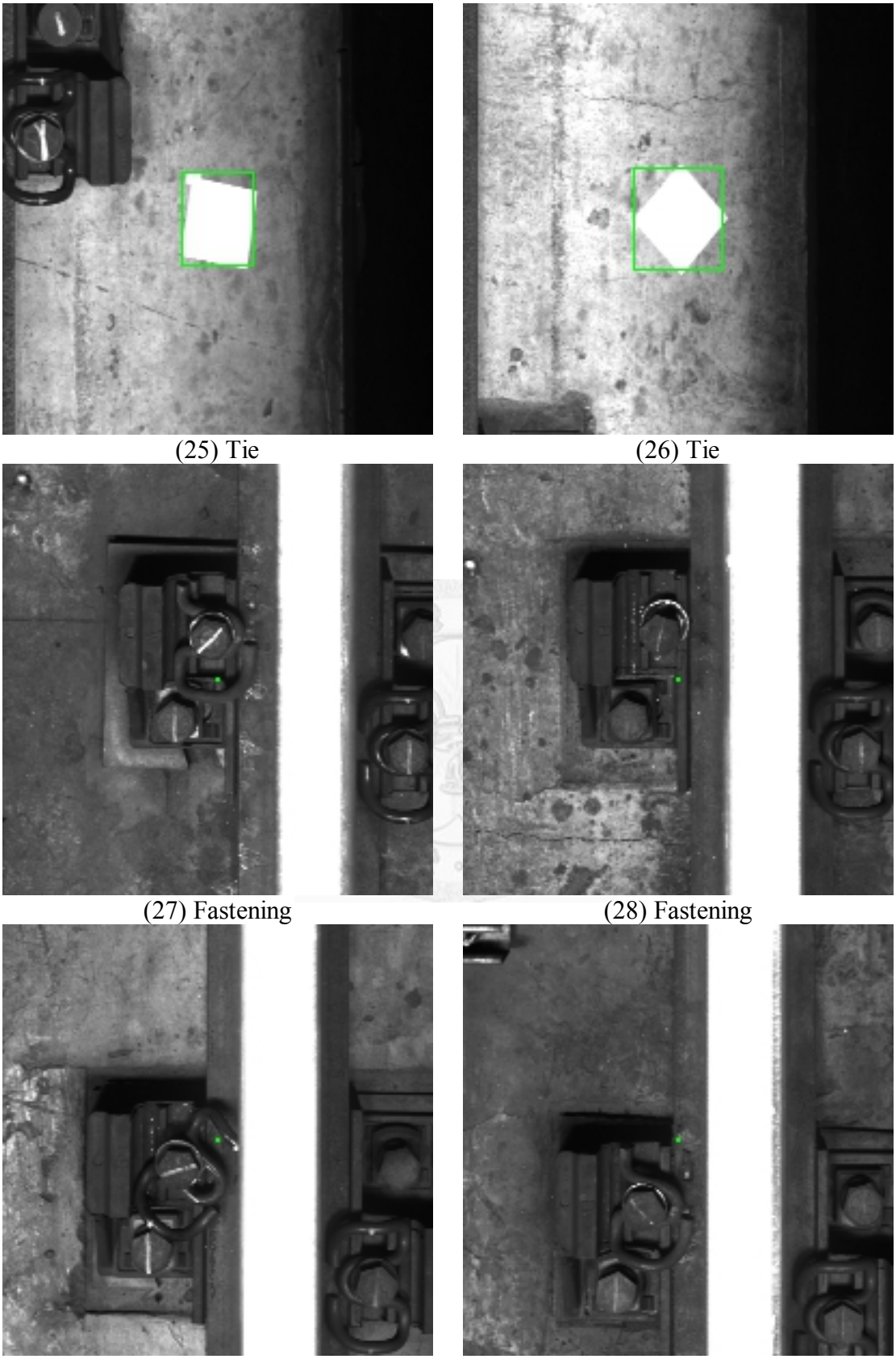


(19) Tie (20) Tie

(21) Tie (22) Tie

(23) Tie (24) Tie

Figure 4.71 Inspected defects in the underground section. Up direction right rail (IV).

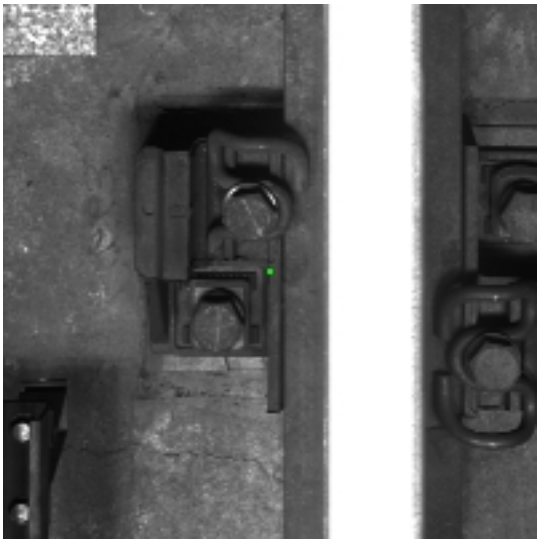


(25) Tie (26) Tie

(27) Fastening (28) Fastening

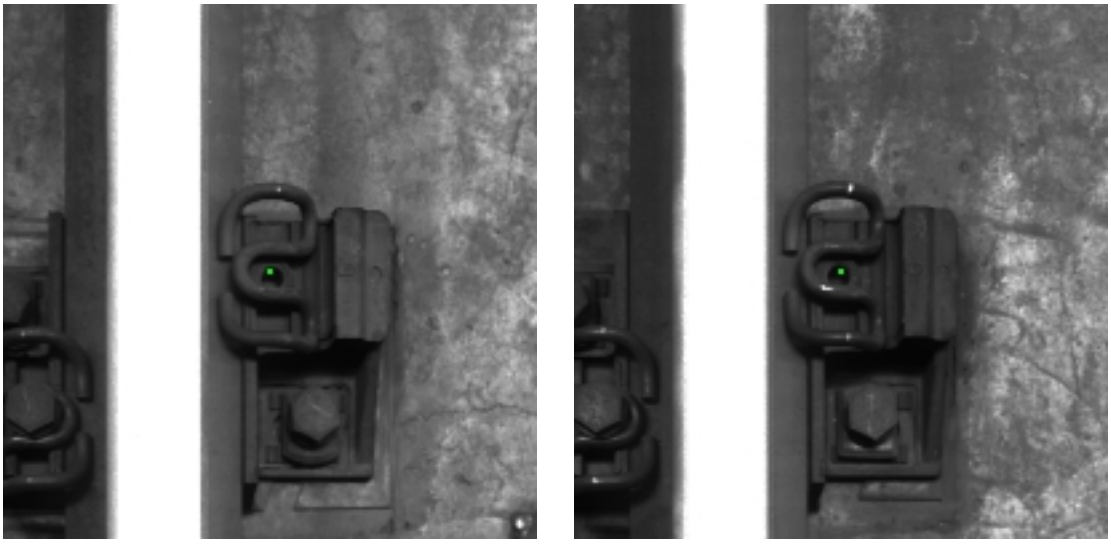
(29) Fastening (30) Fastening

Figure 4.72 Inspected defects in the underground section. Up direction right rail (V).

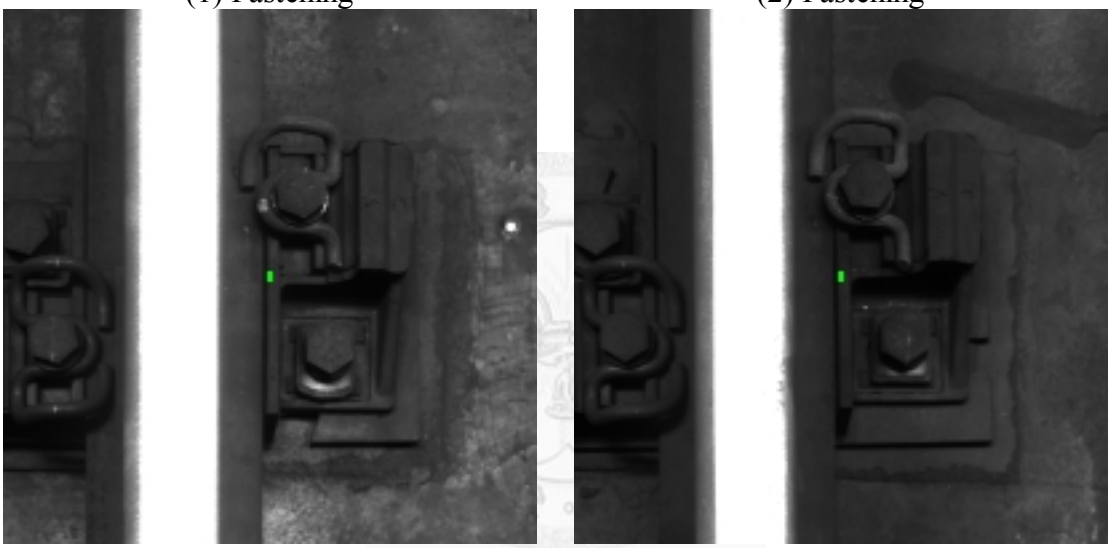


(31) Fastening

Figure 4.73 Inspected defects in the underground section. Up direction right rail (VI).



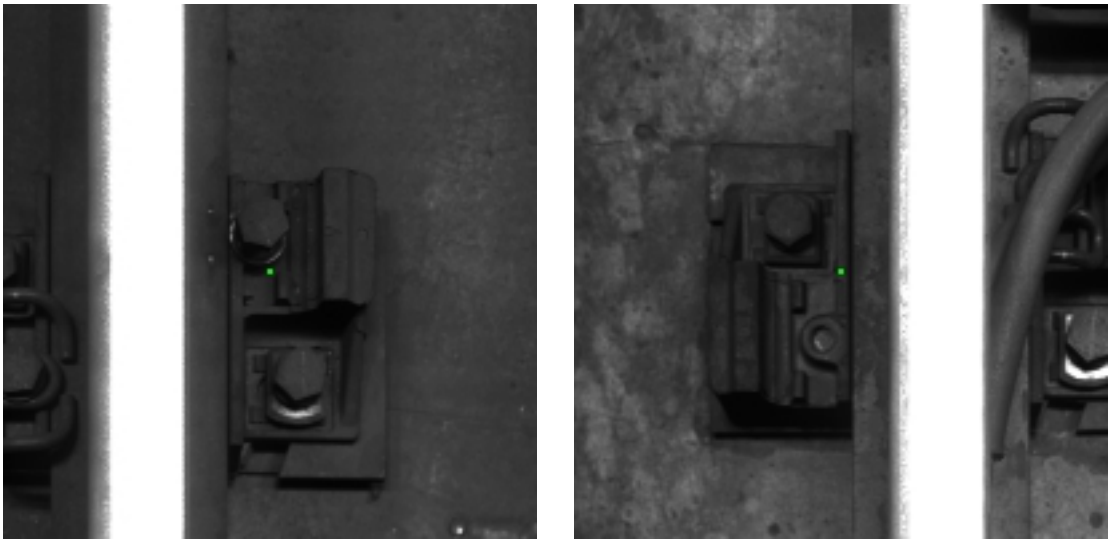
(1) Fastening (2) Fastening



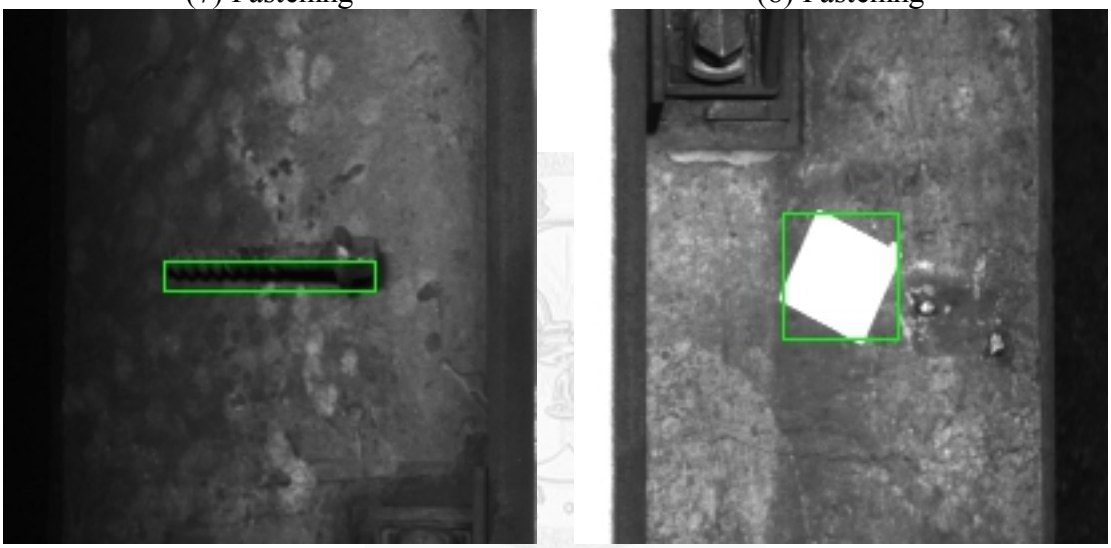
(3) Fastening (4) Fastening

(5) Fastening (6) Fastening

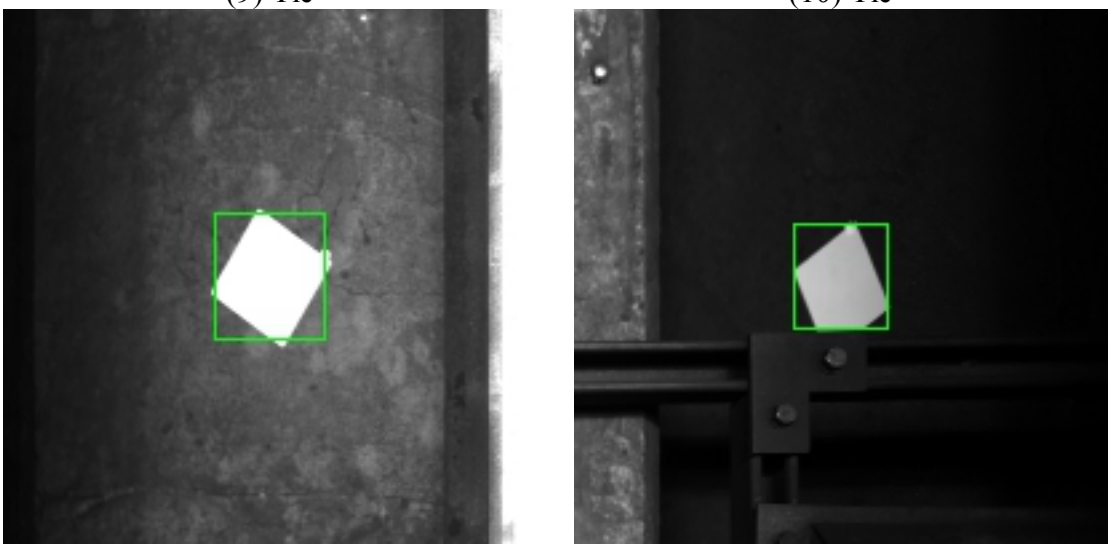
Figure 4.74 Inspected defects in the underground section. Down direction left rail (I).



(7) Fastening (8) Fastening

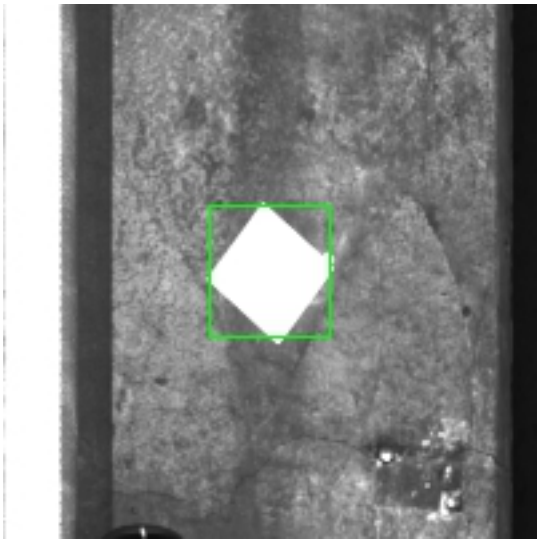


(9) Tie (10) Tie

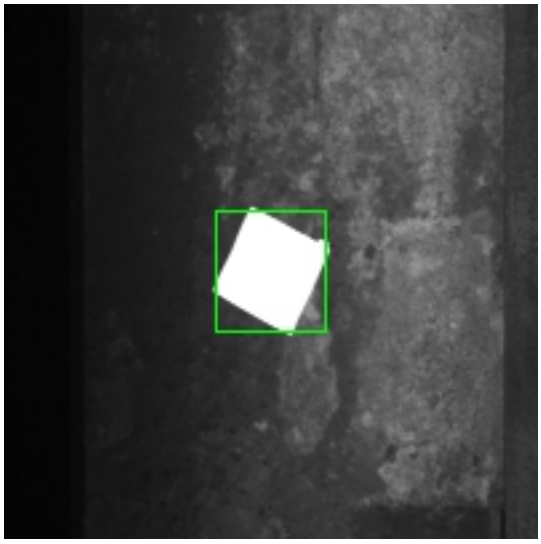


(11) Tie (12) Floor

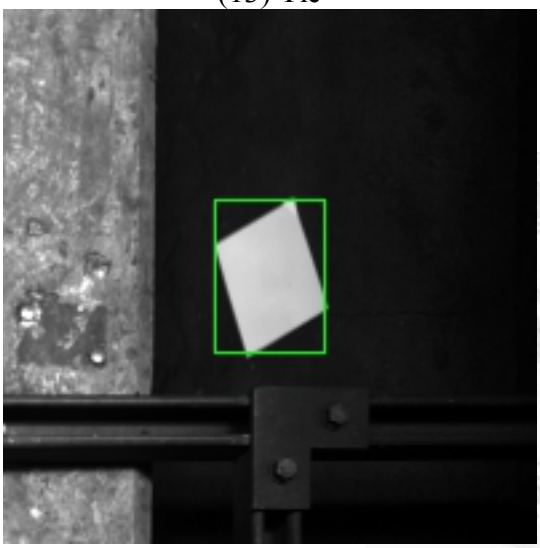
Figure 4.75 Inspected defects in the underground section. Down direction left rail (II).



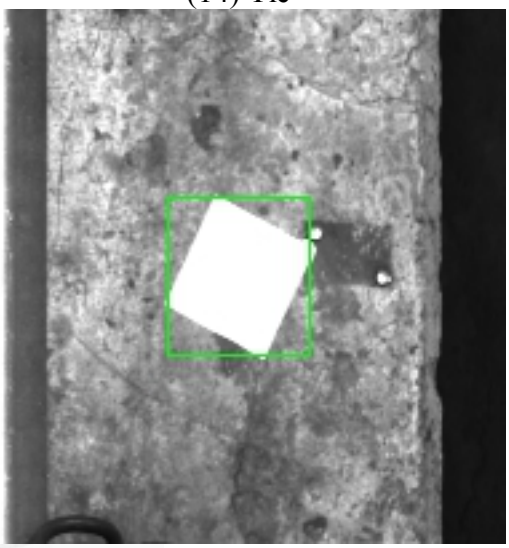
(13) Tie



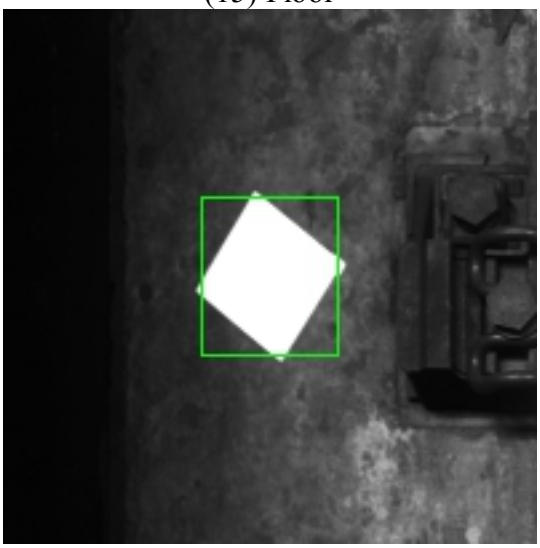
(14) Tie



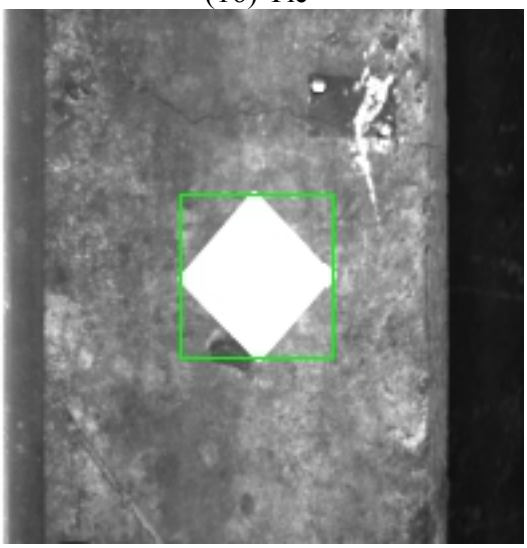
(15) Floor



(16) Tie

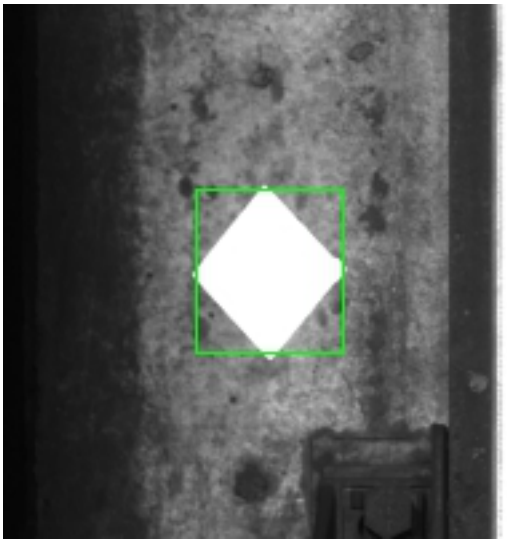


(17) Tie

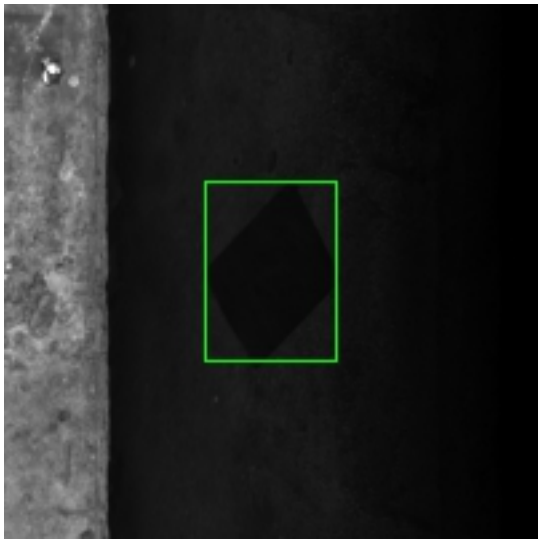


(18) Tie

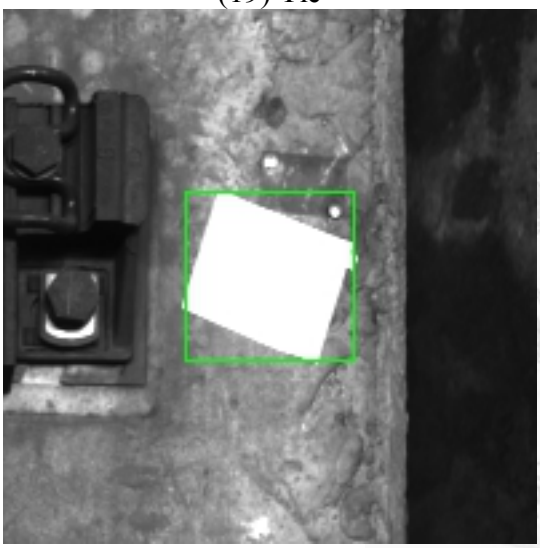
Figure 4.76 Inspected defects in the underground section. Down direction left rail (III).



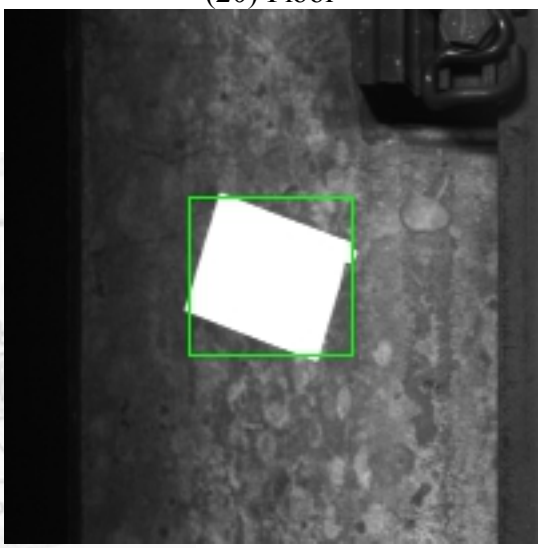
(19) Tie



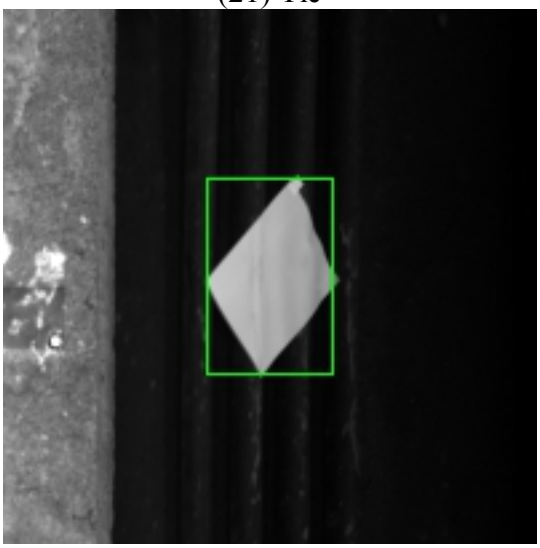
(20) Floor



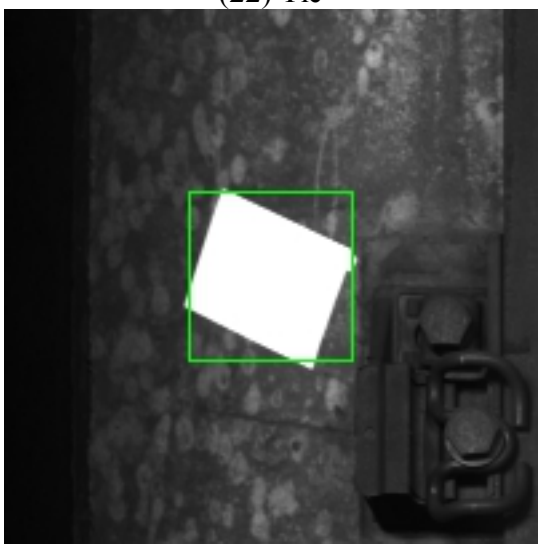
(21) Tie



(22) Tie

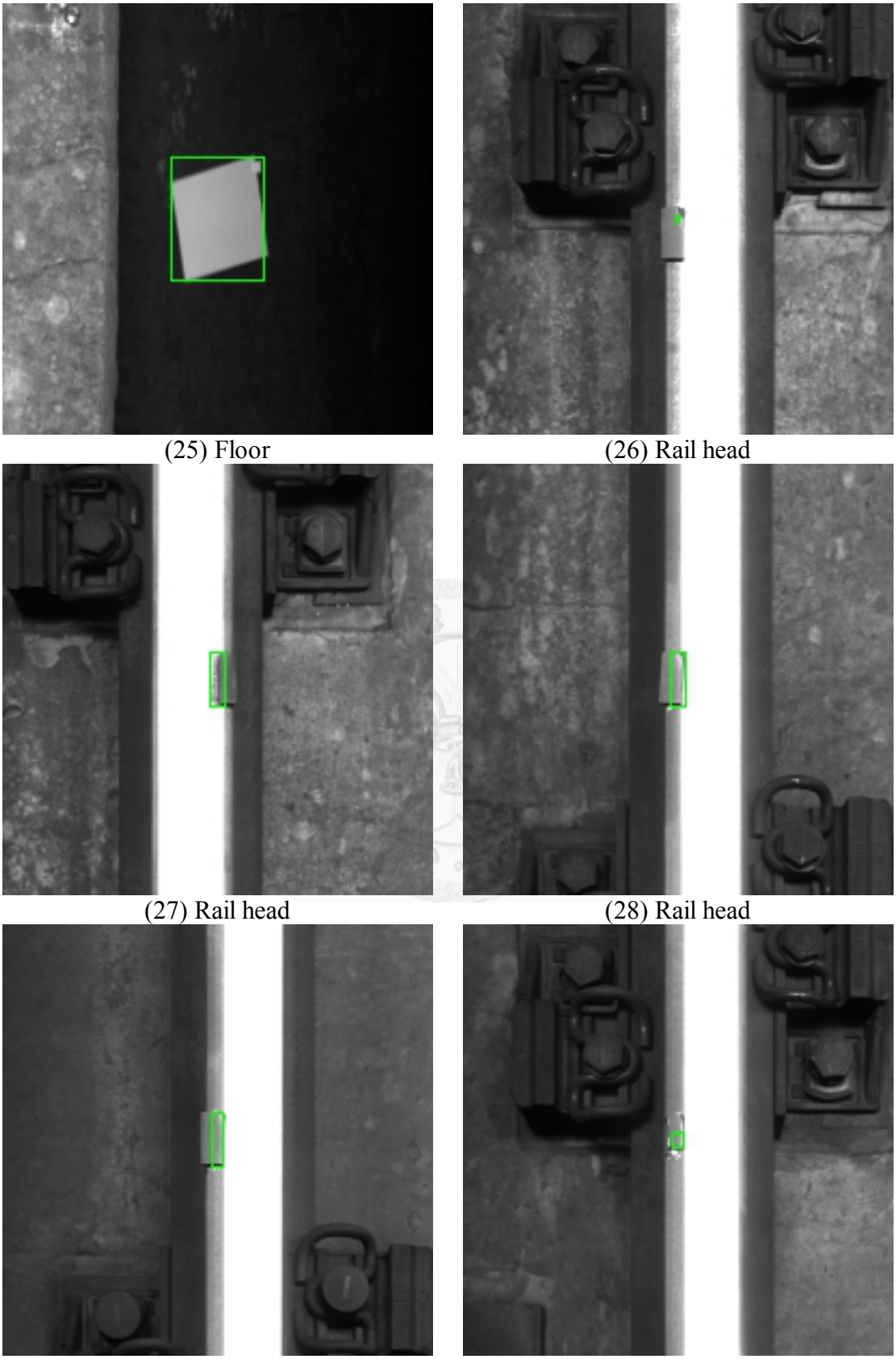


(23) Floor



(24) Tie

Figure 4.77 Inspected defects in the underground section. Down direction left rail (IV).



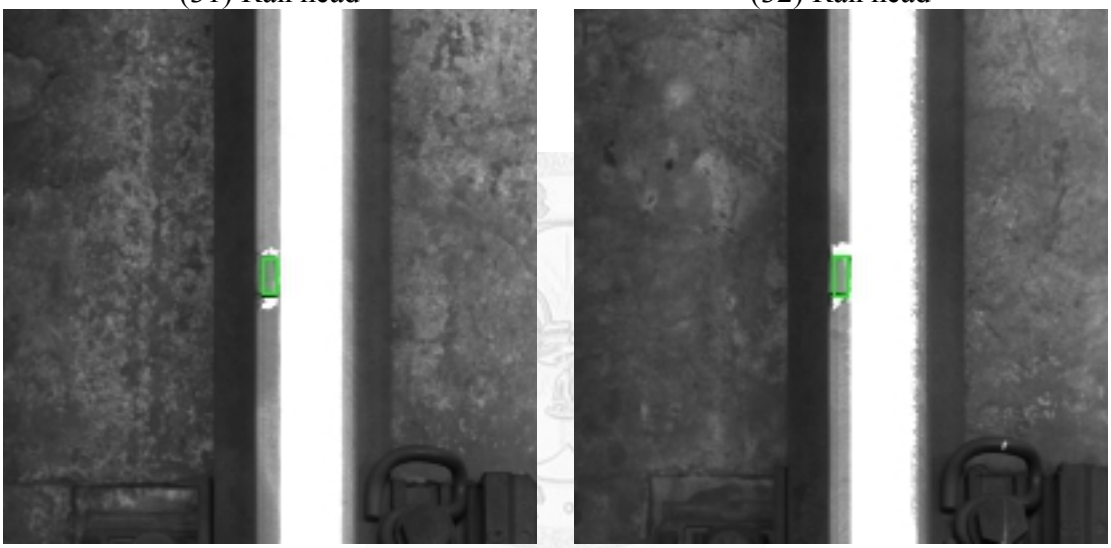
(25) Floor (26) Rail head

(27) Rail head (28) Rail head

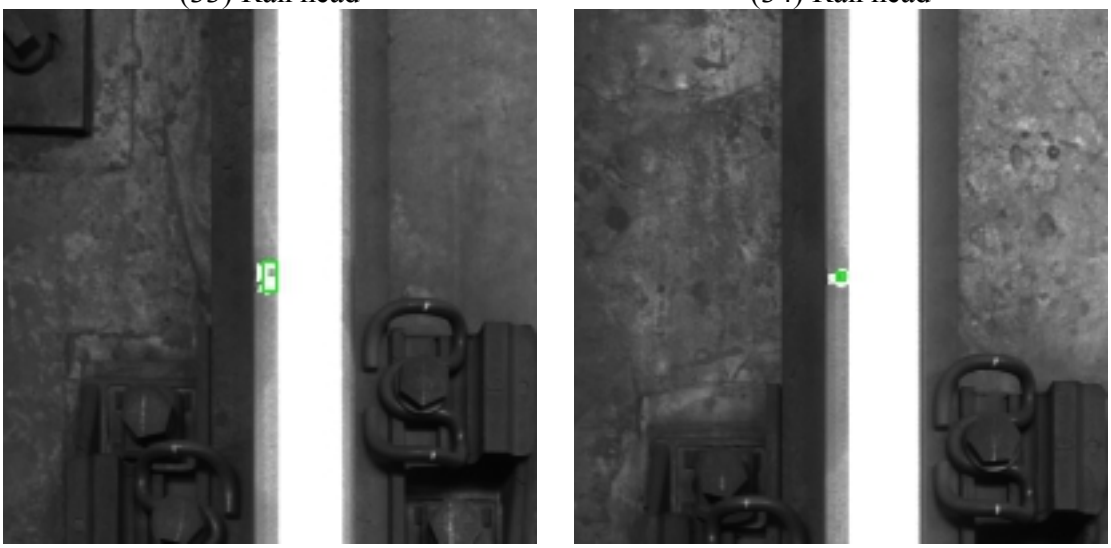
(29) Rail head (30) Rail head

Figure 4.78 Inspected defects in the underground section. Down direction left rail (V).

(31) Rail head (32) Rail head

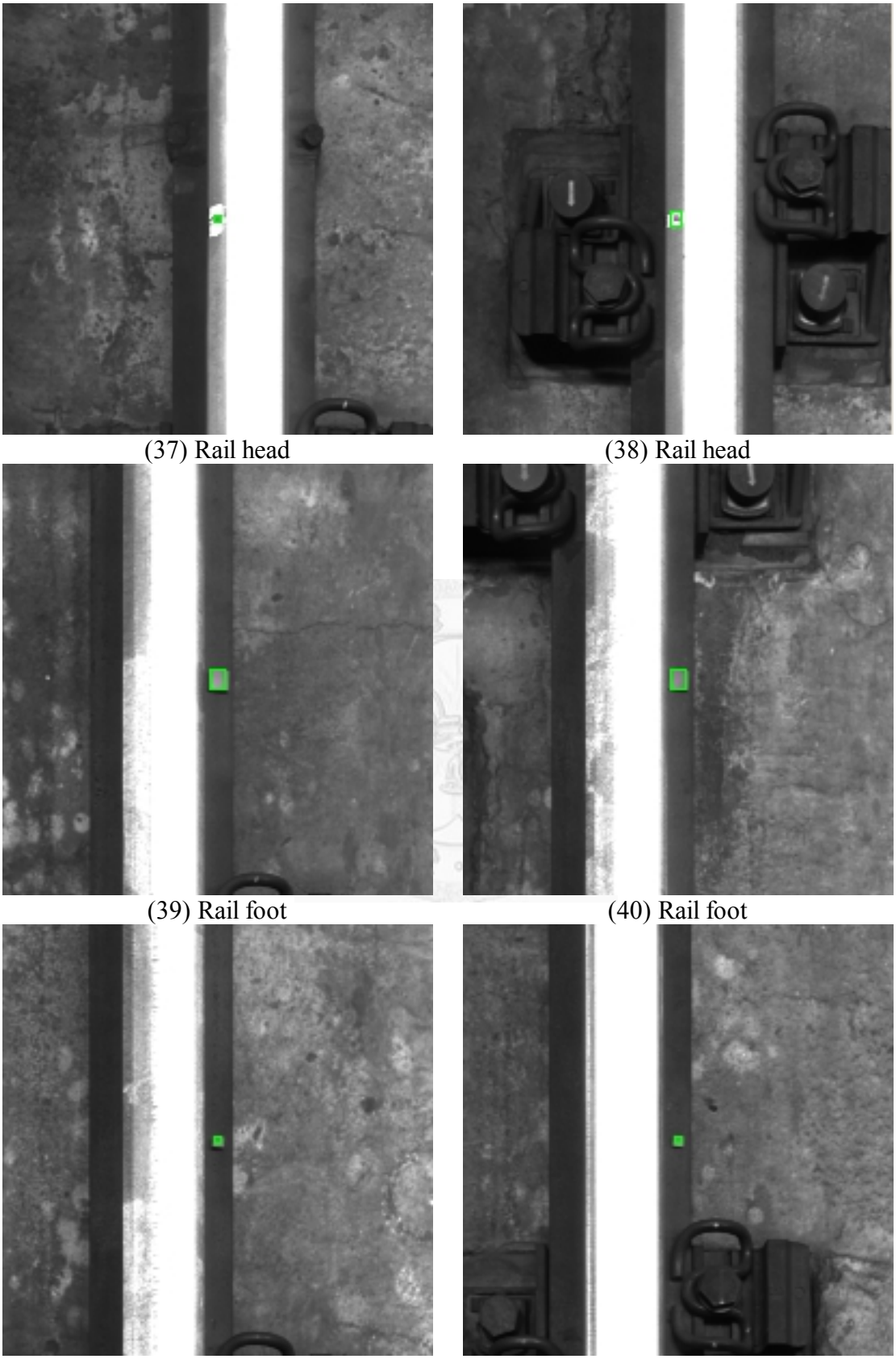


(33) Rail head (34) Rail head



(35) Rail head (36) Rail head

Figure 4.79 Inspected defects in the underground section. Down direction left rail (VI).

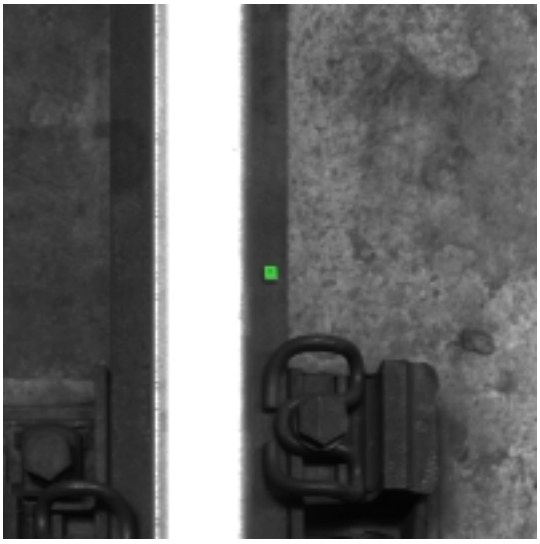


(37) Rail head (38) Rail head

(39) Rail foot (40) Rail foot

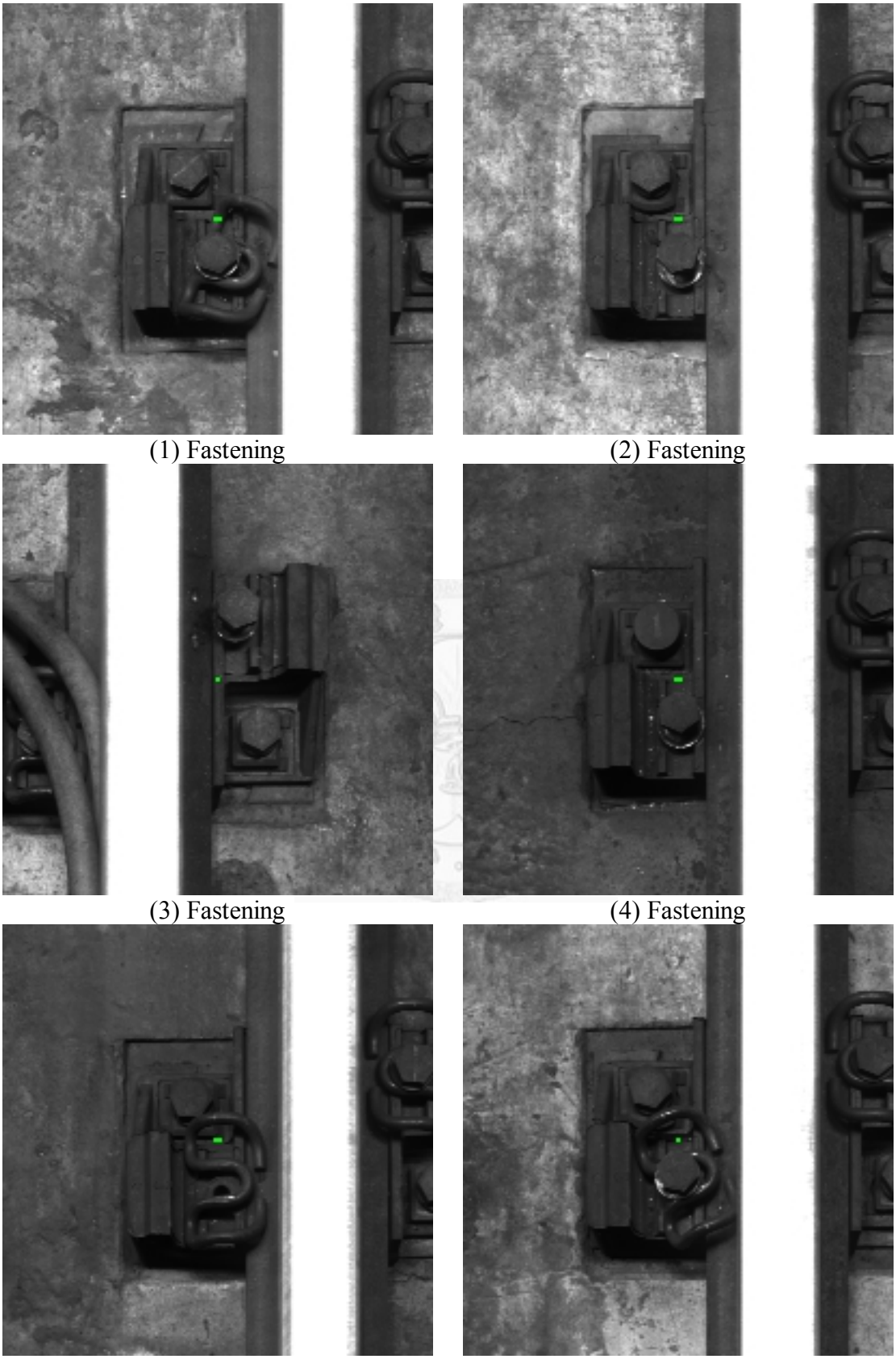
(41) Rail foot (42) Rail foot

Figure 4.80 Inspected defects in the underground section. Down direction left rail (VII).



(43) Rail foot

Figure 4.81 Inspected defects in the underground section. Down direction left rail (VIII).

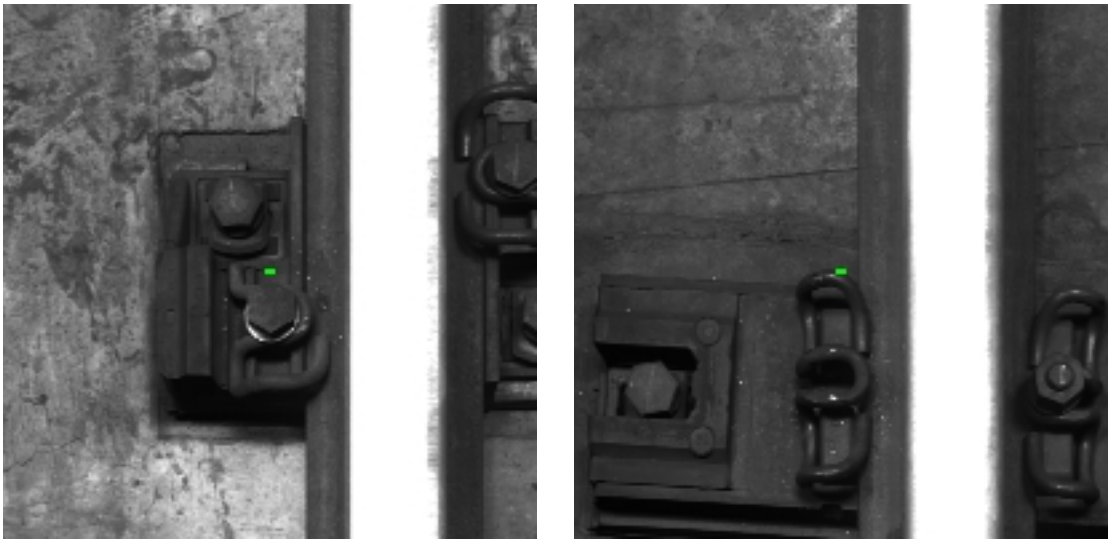


(1) Fastening (2) Fastening

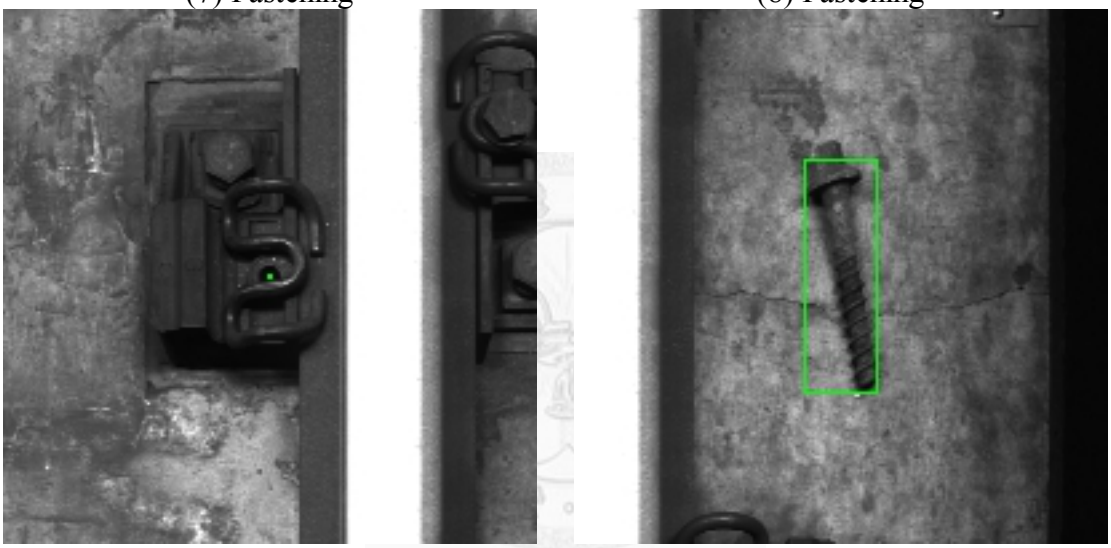
(3) Fastening (4) Fastening

(5) Fastening (6) Fastening

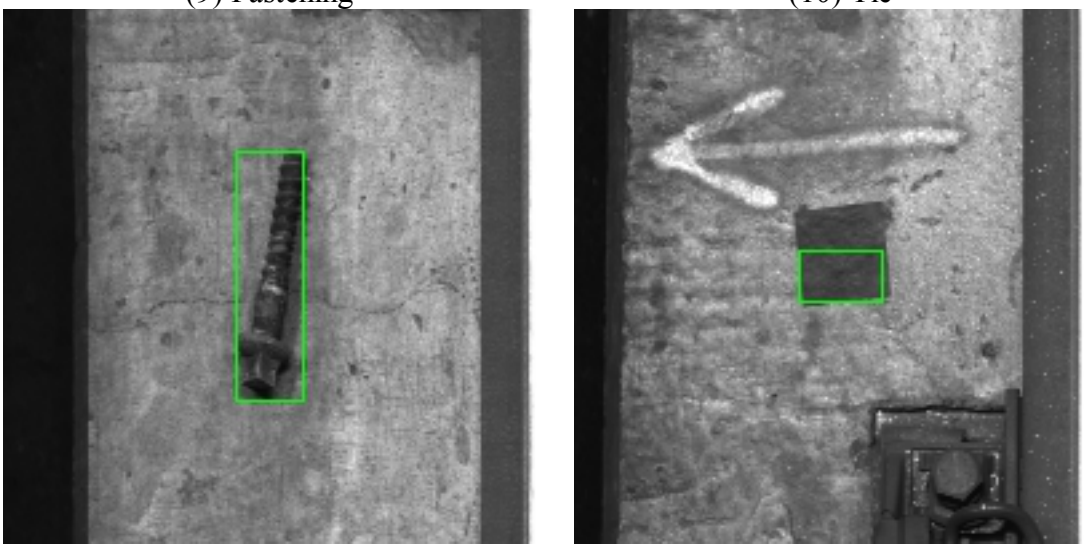
Figure 4.82 Inspected defects in the underground section. Down direction right rail (I).



(7) Fastening (8) Fastening

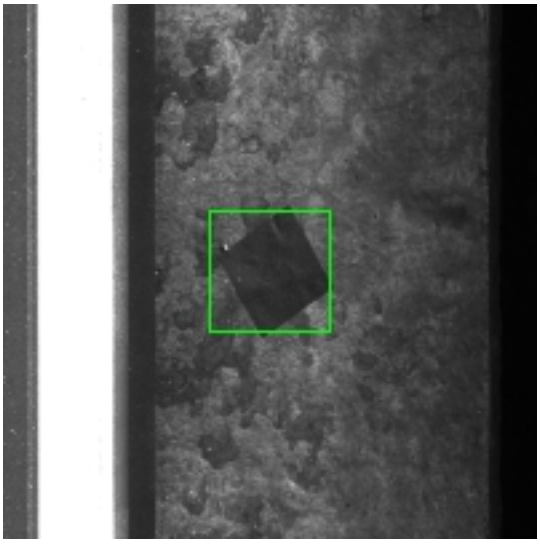


(9) Fastening (10) Tie

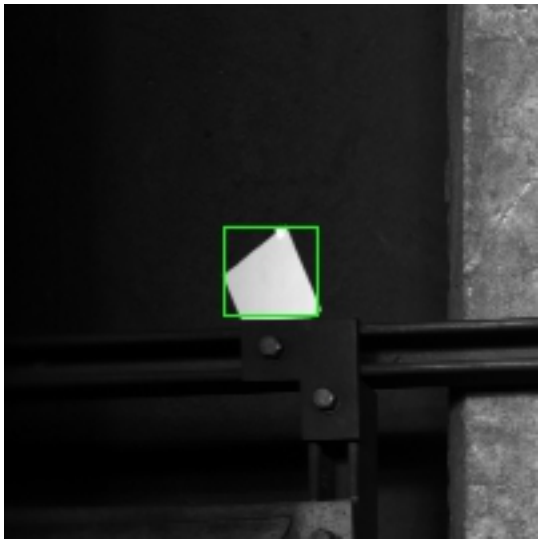


(11) Tie (12) Tie

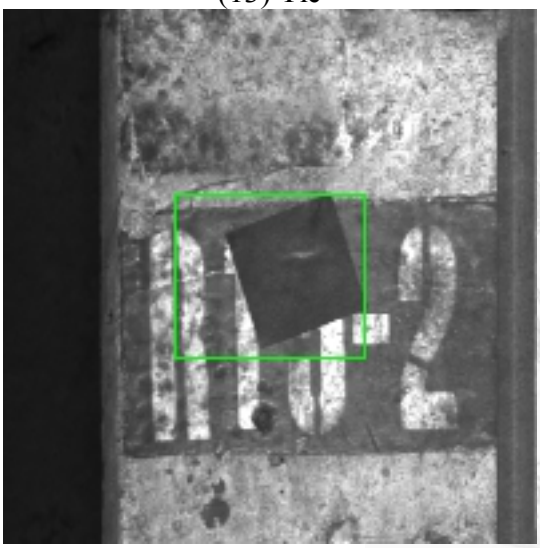
Figure 4.83 Inspected defects in the underground section. Down direction right rail (II).



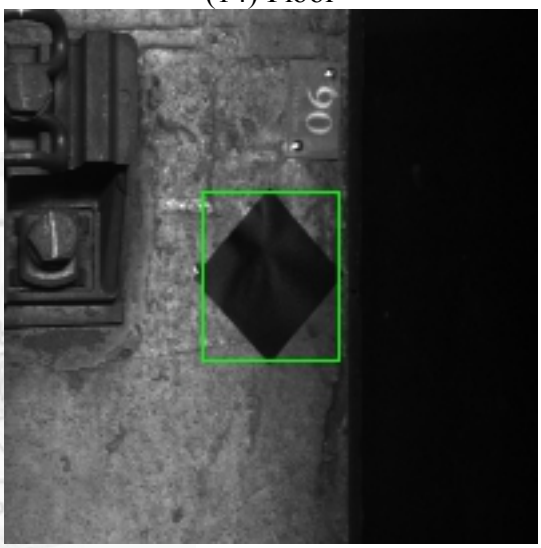
(13) Tie



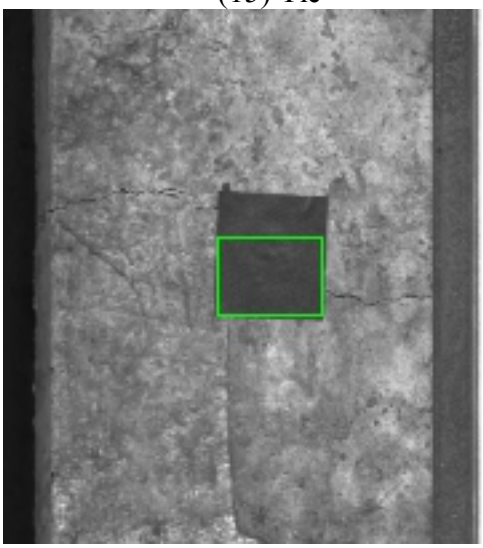
(14) Floor



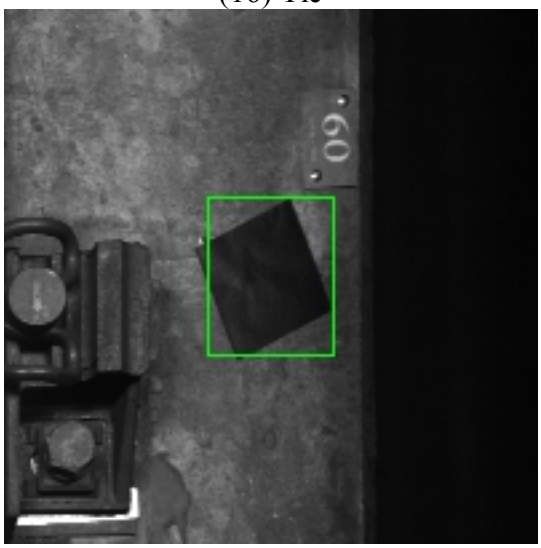
(15) Tie



(16) Tie

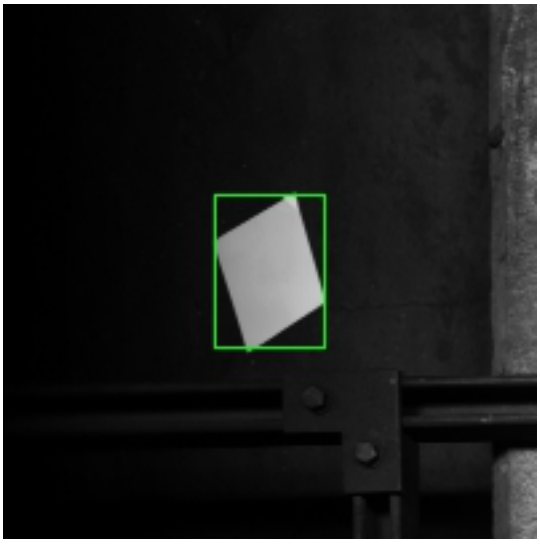


(17) Tie

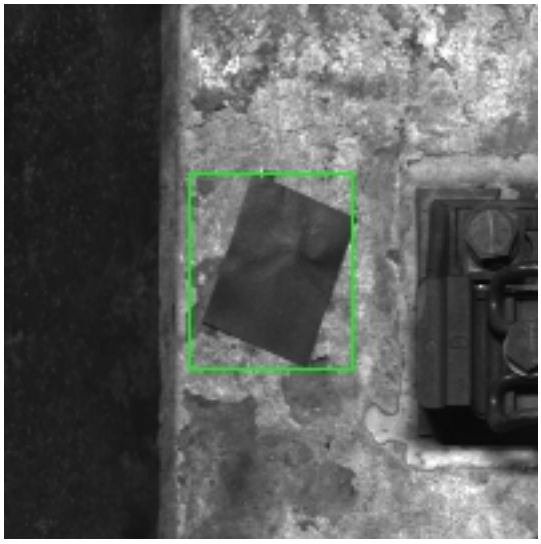


(18) Tie

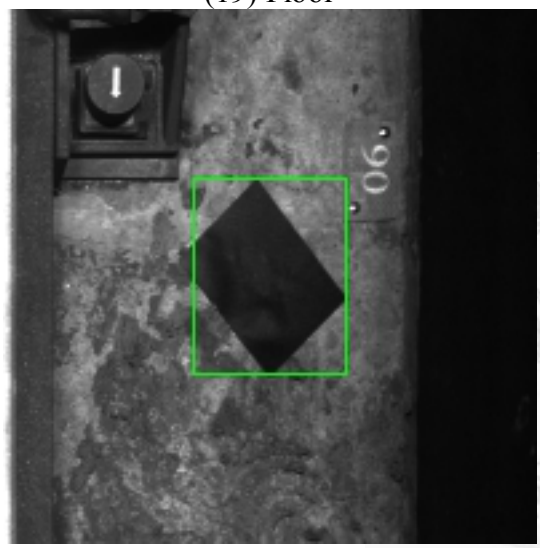
Figure 4.84 Inspected defects in the underground section. Down direction right rail (III).



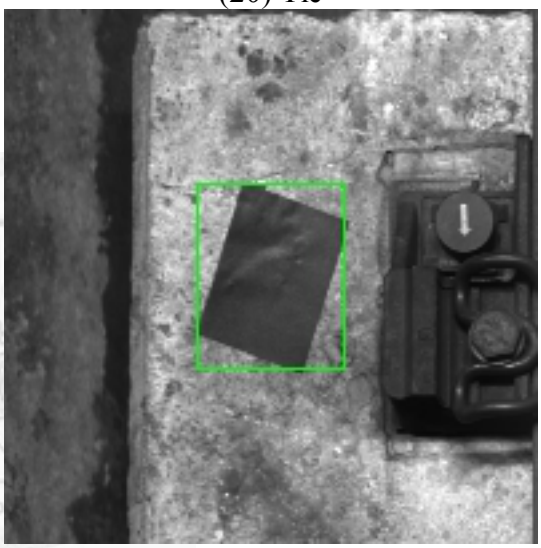
(19) Floor



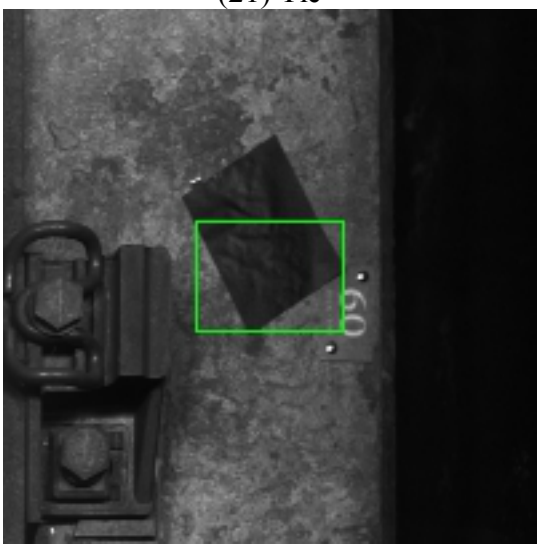
(20) Tie



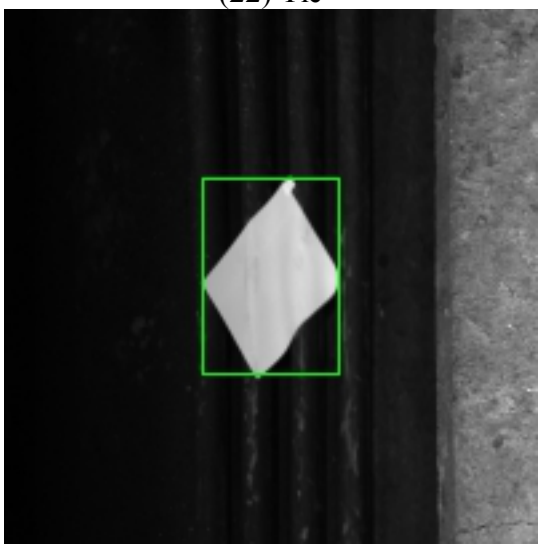
(21) Tie



(22) Tie

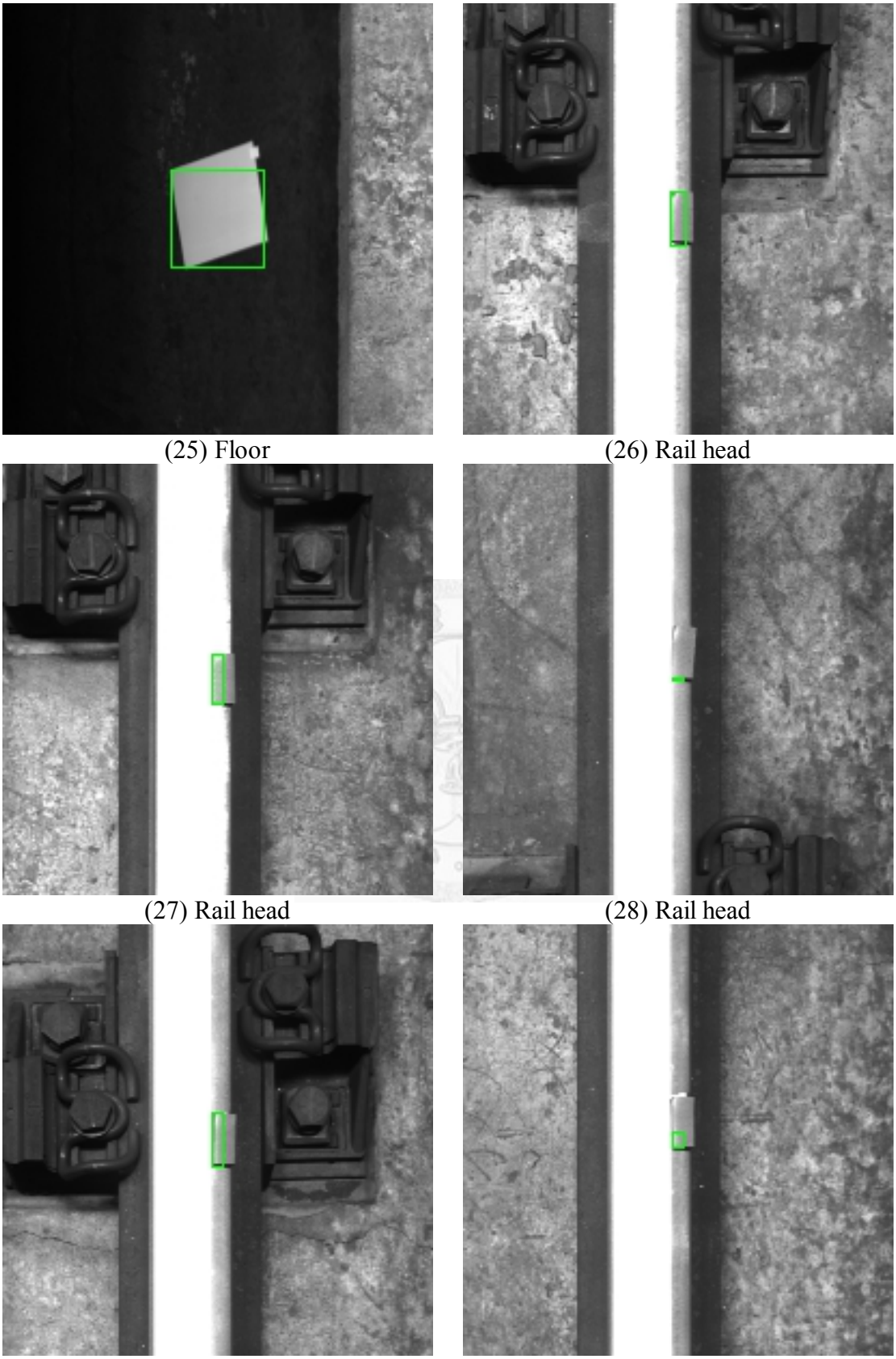


(23) Tie



(24) Floor

Figure 4.85 Inspected defects in the underground section. Down direction right rail (IV).

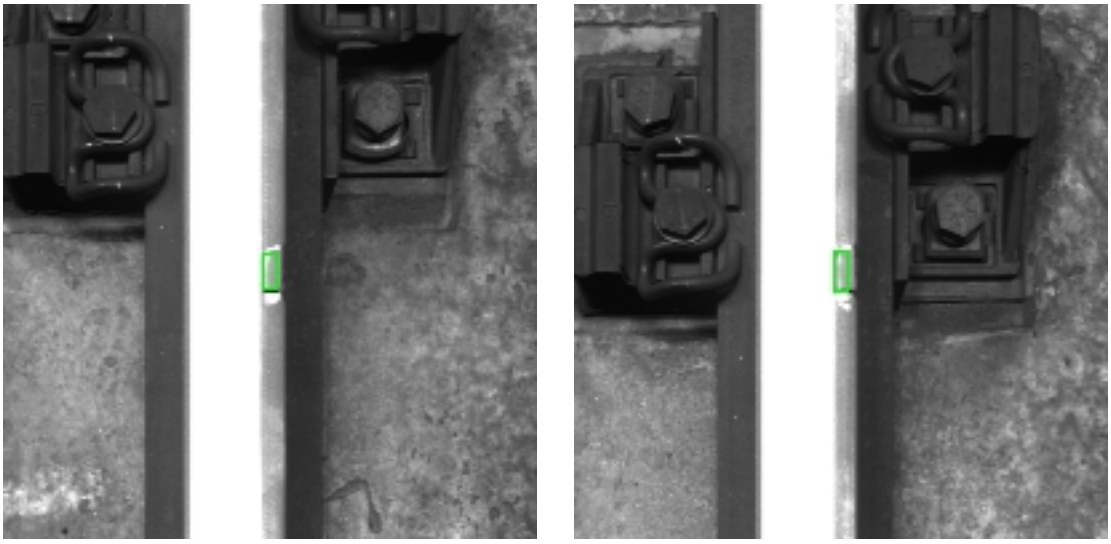


(25) Floor (26) Rail head

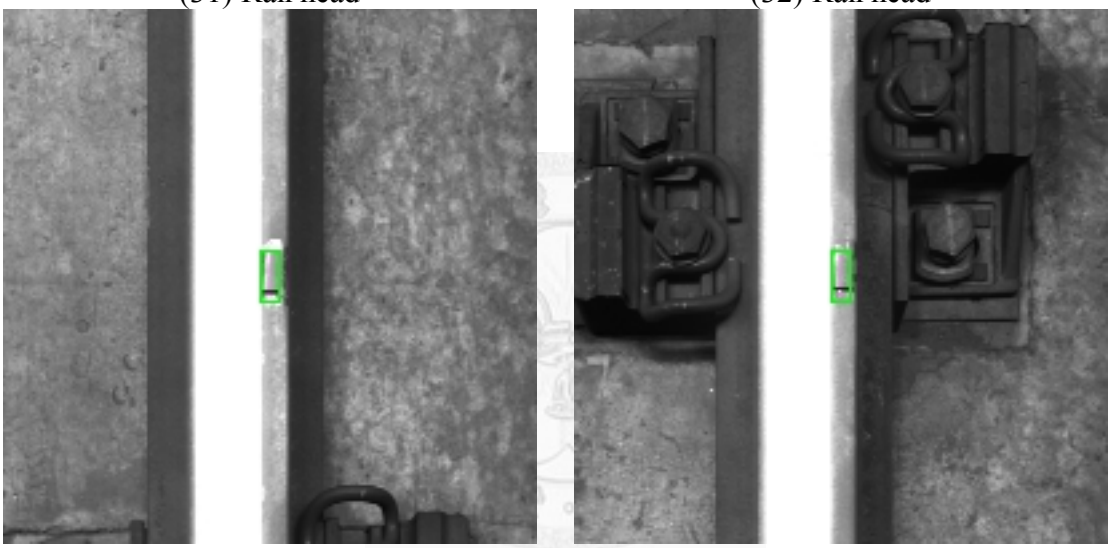
(27) Rail head (28) Rail head

(29) Rail head (30) Rail head

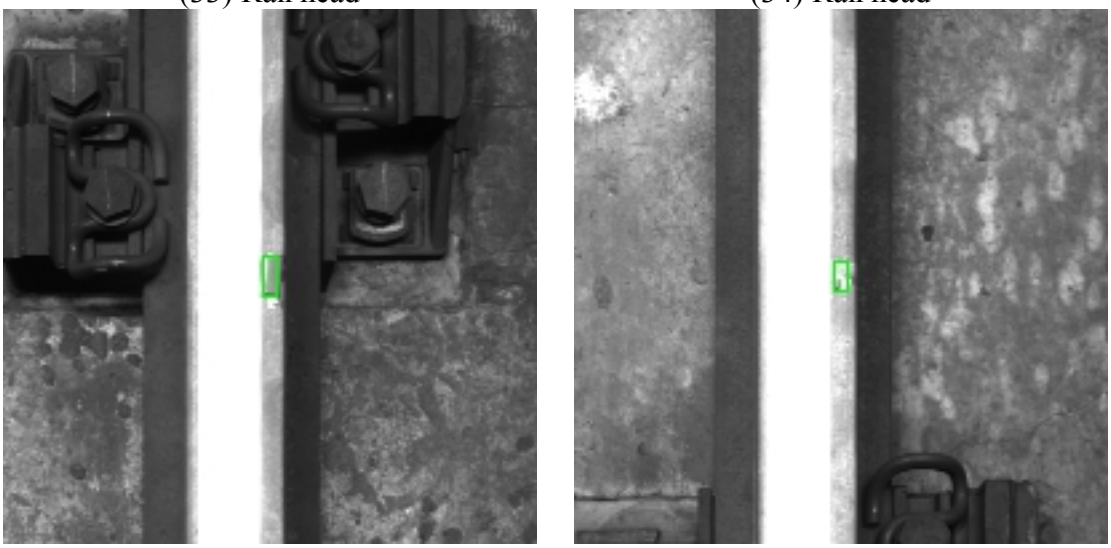
Figure 4.86 Inspected defects in the underground section. Down direction right rail (V).



(31) Rail head (32) Rail head

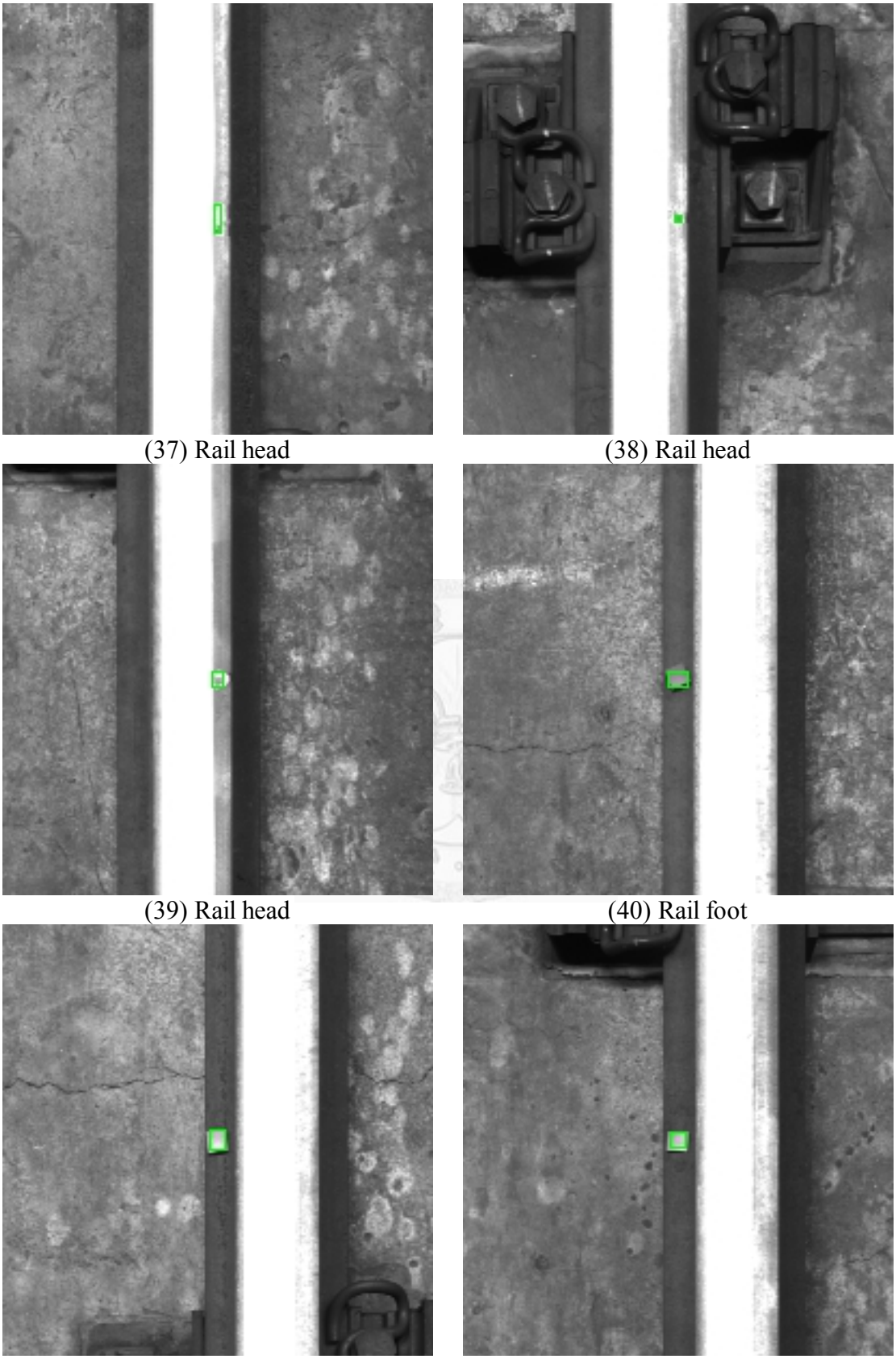


(33) Rail head (34) Rail head



(35) Rail head (36) Rail head

Figure 4.87 Inspected defects in the underground section. Down direction right rail (VI).

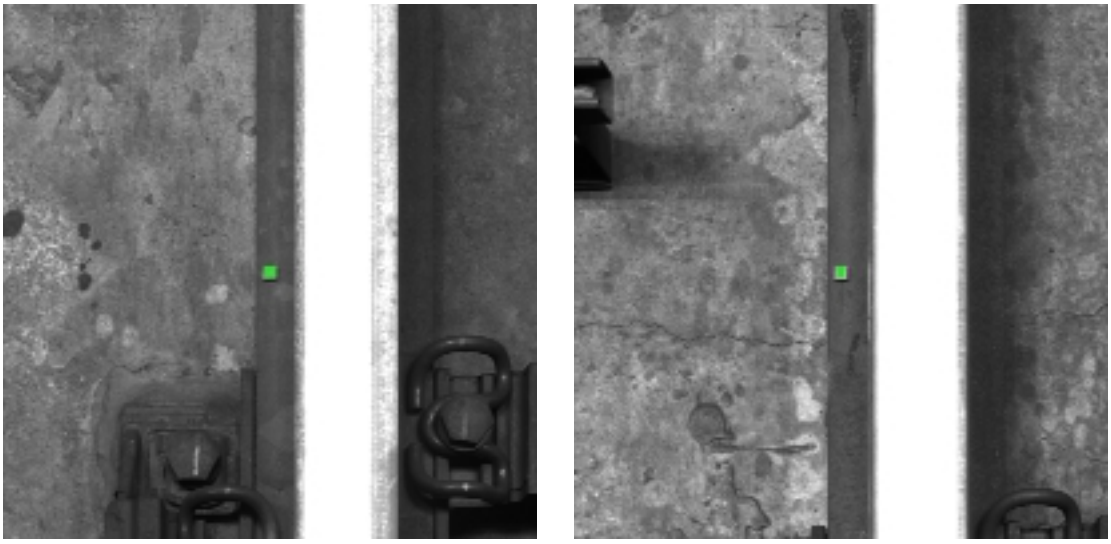


(37) Rail head (38) Rail head

(39) Rail head (40) Rail foot

(41) Rail foot (42) Rail foot

Figure 4.88 Inspected defects in the underground section. Down direction right rail (VII).



(43) Rail foot (44) Rail foot

Figure 4.89 Inspected defects in the underground section. Down direction right rail (VIII).

# Chapter 5 Extensions

## 5.1 Defect Classification

To display the information of the inspected defects in detail, a further classification is necessary. By the classification, user can obtain statistics in each class so that user can analyze the information of railroad in a better way. We select some classes of defects that user possibly focuses on. These classes are shown in Figure 5.1.

| Zone | Classes of Defects |
|---|---|
| Rail Head | Break, Wheel-Caused Abrasion, Wavy Abrasion, Oil Stain, and Undefined. |
| Rail Foot | Oil Stain and Undefined. |
| Fastening | Retaining Ring Defect, Screw Bolt Defect, Base Plate Defect, and Undefined. |
| Tie | Break, Foreign Matter, Sign Card, and Undefined. |
| Ballast or Floor | Foreign Matter and Undefined. |

Figure 5.1 Defect Classification

## 5.2 Definition of Each Defect Class

- Rail-head zone
  - Break: a dark defect which is a crack cutting off rail head.
  - Wheel-caused abrasion: a bright defect because rail head suffered a heavy force from wheel.
  - Wavy abrasion: a dark defect because rail head suffered an uneven force when train is running.
  - Oil stain: a dark defect which is oil on rail head.
- Rail-foot zone
  - Oil stain: a dark defect which is oil on rail foot.
- Fastening zone
  - Retaining ring defect: a defect on fastening retaining ring.
  - Screw defect: a defect on fastening screw.
  - Base plate defect: a defect on fastening base plate.
- Tie zone
  - Break: a dark defect which is a crack cutting off tie.
  - Foreign matter: a defect which is a foreign matter to railroad in tie zone.
  - Sign card: a bright defect which is a sign card to mark information.
- Ballast or floor zone
  - Foreign matter: a defect which is a foreign matter to railroad in ballast zone.

## 5.3 Classification Logic

Our desired inspection system does not only include defect inspection but also defect classification. However, classification is subjective for some classes such as oil stain or break. Hence, we provide many adjustable parameters to assist user to determine the classification. The parameters include width, height, aspect ratio, area, mean grayscale value, and angle. Below, we describe our classification logic for each inspection zone in detail.

For the defect classification in the rail head zone, we need to analyze the location of each inspected dark defects. If some of them are near and centralized in a small width range, and the number of these defects is more than the limit value for wavy abrasion, then they are considered as wavy abrasion. If a dark defect is not in a wavy abrasion, we check whether it touches both rail head bounds. If it does, this dark defect is classified into the break class. The remaining dark defects are classified into the oil stain class or not classified according to the oil stain limit parameters. Similarly, the bright defects are classified into the wheel-caused abrasion class or not classified according to the wheel-caused abrasion limit parameters.

For the defect classification of the rail foot zone, we only need to check whether each inspected dark defect is an oil stain or not. The classifier is implemented according to the oil stain limit parameters.

To classify fastening zone defects, we check whether defects are on every part: the upper retaining ring part, the lower retaining ring part, and the screw bolt part. If it is true, we classify all defects as base plate defects. Otherwise, they are classified into corresponding classes according to location.

To classify tie zone defects, we classify dark defects for the break class and bright

defects for the sign card class first. Similar to the break class in the rail head zone, we check whether the dark defect touches two of the edges of tie. If it does, this dark defect is classified into the break class. The bright defect is classified into the sign card class if its angle is close to zero because the sign card is orthogonal to the bound of rail head. The remaining defects are classified into the foreign matter class or not classified according to the foreign matter limit parameters.

The last is the ballast or floor zone. The inspected defects are classified into the foreign matter class or not classified according to the foreign matter limit parameters.

Any defect is not classified in five zones is classified into the undefined class.

# Chapter 6 Future Work

Although the result statistics show an acceptable inspection rate, many false alarms appear. To inspect the subtle defects, many non-defect objects are mistaken as defects too. Most of them are due to the instability of the appearance of inspection zone. Some objects such as pipes, metal plates, cables, or other system facilities are mistaken as defects too. False alarm is an essential issue to be solved in the future.

The fastening inspection has an essential issue to be solved too. We inspect fastenings by the shadows of their retaining rings. However, some fastenings may have no shadows in our captured images. We cannot inspect the retaining ring parts of the fastenings with no or subtle shadows. Thus we need to adjust or extend our fastening inspection logic.

We inspect the page with track switch in only two inspection zones: rail-head zone and non-rail-head zone. However, the division of zones is not accurate enough for fine inspection. This is another inspection issue we need to solve.

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