Ⅰ－20　A STUDY ON THE QUALITY OF CAD DRAWINGS OF EXPRESSWAYS AND ADDITION OF LANE MARKING DATA

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Abstract: Conversion of a CAD drawing of the horizontal geometry plan of a road to GIS data is a promising way for realizing almost real time generation/updating of digital road maps. In Japan, the collection of CAD drawings of expressways and national highways has begun recently. In order to utilize this collection, it is necessary to assess the quality of these drawings. More than fifty CAD drawings of a stretch of an expressway with 50 km in length were used for this assessment. Whether end points of same line segments that should intersect on the dividing line between adjoining drawings really intersect on that line was checked first. It was found that the difference between two end points is less than one millimeter in an absolute size in most cases. In many of the collected drawings of expressways, lane markings are not drawn. However, lane markings are necessary for lane-level navigation and safe driving assistance and therefore a handy and inexpensive method to obtain the geometry of lane markings was sought. It was found that their geometry can be obtained with precision by drawing parallel lines with the center line of an expressway. Following these, the coordinates of objects on a CAD drawing were compared with the absolute coordinates measured by a digital aerial triangular survey. The objects evaluated include the boundary of a carriageway, the entrance of a tunnel, elevated bridges that are crossing over an expressway and so on. About eighty percent of all measured objects have the CAD coordinates with the difference less than 1.7 m in comparison with the absolute coordinates. This difference is almost equivalent to the accuracy of a map with the scale of 1 to 2,500.

Keywords: 2D CAD drawings of expressways, data quality, location accuracy, addition of lane markings

1. INTRODUCTION

GIS data of roads are necessary in various ITS (Intelligent Transport Systems) services including vehicle navigation, safe driving assistance and maintenance of roads, to mention a few. Frequent updating of GIS data is also required that reflects the change of road alignment, lane widths, the number of lanes and the like to provide users with latest information. The need for speedy updating is greater and more pressing in the field of vehicle navigation.

Link level information of roads will suffice for conventional ITS services like car navigation and traffic information provision. However, advanced ITS services require lane level information. For example, *Road Safety Programme 2011-2020*[1)], adopted by the EU Commission recently and aiming at cutting road deaths in Europe in half in the next decade, includes mandatory lane departure warning systems as one of pillars of safety measures for vehicles. In addition, Working Group 14 (WG 14) of ISO/TC204, that is responsible for the standardization of ITS, is now discussing a ‘Lane Keeping Assist System’ (LKAS) that recognizes forward lane markings and assists drivers to drive keeping in a lane[2)]. Lane marking data are essential for the realization of this system.

It is possible to obtain lane marking data by driving a measurement vehicle equipped with cameras, laser scanners and other instruments[3)]. However, the cost and time required for this measurement are considerable. Therefore, alternative measures should be sought.

Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has been promoting CALS/EC (Continuous Acquisition and Life-cycle Support/Electronic Commerce) and, as a result of this activity, electronic deliverables are accumulated[4)] that include horizontal geometry plans of national highways drawn by CAD software. With respect to expressways, horizontal geometry plans were collected just

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before Japan Highway Public Corporation was privatized in 2005. Utilization of these deliverables has been actively studied recently[5, 6]. Among these studies, there is a Comprehensive Technology Development Project entitled 'Development of national surveillance system to reduce damages of disasters[7]' and more rapid and advanced updating of fundamental geospatial data was investigated[8] by the Information Technology Division of National Institute for Land and Infrastructure Management (NILIM) and Geospatial Information Authority (GIS). In this R & D project, where one of us was engaged, the accumulation of fundamental geospatial data through the transformation of CAD drawings of road works into GIS data was studied[9]. Unfortunately, this study is confined to national highways and expressways are not included. Apart from this, the pioneering study by Yamasaki, Yoshida et al.[10] that developed Japan Highway Data Model (JHDM) is worth noting. In this study, the alignment information on a completion road was restored from the alignment figure.

The primary focus of this paper is on the restoration of lane markings of expressways. There are two reasons for this. The first one is that the needs for these data are becoming greater as mentioned above. In addition to this, lane markings are not drawn in many of the CAD drawings of the horizontal geometry of expressways at our hands. Therefore, it is necessary to investigate whether it is possible to restore lane markings from these CAD drawings and how accurate the results are.

In dealing with expressways, there is a restriction that does not exist in national highways. That is, it is almost impossible to go into an expressway and to make measurements because of traffic regulations these measurements inevitably involve. We have tried to make measurements at the same time when a maintenance work such as weeding or repavement is carried out but in vain. The length of these maintenance works is short in most cases and their dates are dispersed. An alternative is the use of elevated bridges but they rarely exist in flatlands[10]. As a last resort, we have used a digital aerial triangular survey to obtain a true position of lane markings and objects. This is not an inexpensive method but if the results of the restoration of lane markings and the positional accuracy of objects are satisfactory, the aerial survey will be no longer necessary.

2. COLLECTION OF CAD DRAWINGS OF ROAD WORKS AND THEIR CONVERSION

In order to realize frequent updating of road data, we have proposed the conversion of CAD drawings of the horizontal geometry plan of a road drawn just after a road construction work to GIS data[11]. In line with this proposal, a manual for the making of CAD drawings for road works was compiled[12]. In this manual, it is specified that the horizontal geometry plan of a road be drawn by CAD software and stored in the SXF (Standard CAD data exchange format in Japanese Construction Field) format that is used for an exchange of CAD data.

After these preparations, the collection of CAD drawings for national highways began in 2006 and now about twenty percent of national highways are covered. In contrast to this, almost all CAD drawings of expressways have been already collected. The scale of drawings is 1 to 500 for national highways and 1 to 1,000 for expressways except interchanges or parking areas. For interchanges and parking areas, the scale is 1 to 500. These scales are large enough to identify the detailed alignment and lanes of a road and road facilities. An example of CAD drawings of an expressway is shown in **Fig. 1**. Each drawing covers 800 meters in length. Dividing lines, that are the boundary of adjoining drawings, exist on both sides of each drawing and are expressed as a broken line.

There are some differences between CAD drawings of national highways and those of expressways. First, CAD drawings of expressways do not comply with the manual for the making of CAD drawings[12] mentioned above. Therefore, the CAD-GIS convertor for national highways[13] cannot be used for expressways readily. Some preprocessing may be necessary. Second, the coordinates of milestones have been recently measured[14] for national highways and these milestones can function as a reference point for position adjustment. However, the coordinates of milestones have not been measured for expressways and they cannot function in the same way. Last, in relation to the second point, the CAD drawings prepared by NEXCOs have coordinates that correspond to Japanese Geodetic Datum. However, the coordinates themselves are not based on the on-site measurements, but positions are adjusted on the basis of the calculated results of a center line. Therefore, it is necessary to investigate the accuracy of this adjustment.

The overall process of conversion of CAD drawings to GIS data is described in **Fig. 2.** The conversion process consists of the following five steps:

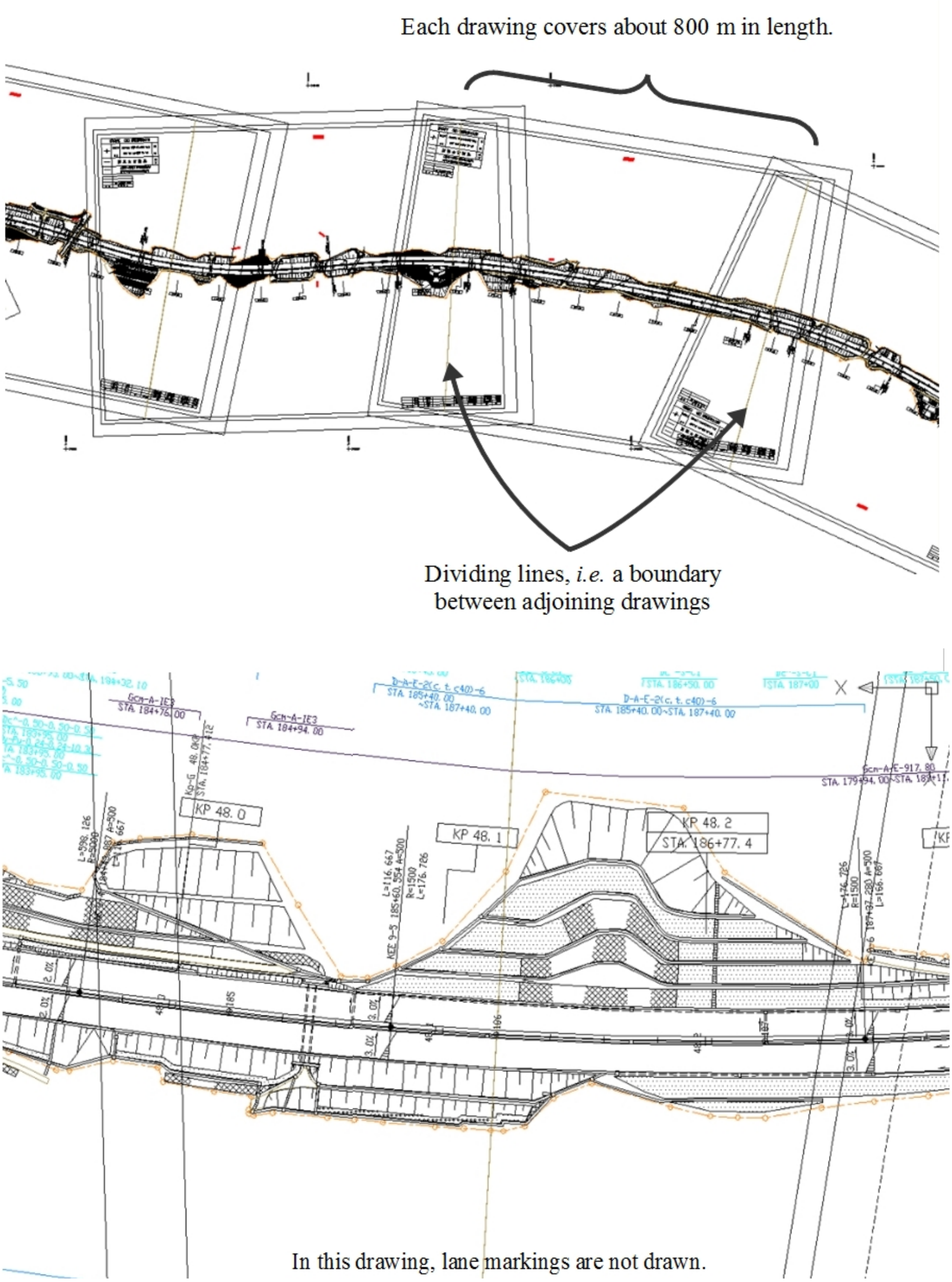


Fig. 1 An Example of a CAD Drawing
(Above: Relationship of Drawings, Below: Detailed Drawing)

- [Step 1] Check of missing drawings: If there are any missing drawings, obtain necessary drawings.
- [Step 2] Check of the consistency on the dividing line of adjoining drawings: Correction of errors is made if there are any. In this step, whether end points of same line segments intersect on the dividing line of the adjoining drawings is checked. If the two end points do not intersect on the dividing line, then a correction is made.
- [Step 3] Addition of required information such as location of lane markings, traffic signs and so on.
- [Step 4] Correction of the locations of objects on CAD drawings and combination of drawings. The correction of the location of an object can be made before or after the combination of drawings.
- [Step 5] Conversion to GIS data.

In this paper, following issues are addressed that are related to Steps 2, 3 and 4 above:

1) Do the end points of two same line segments that should intersect on the dividing line between two adjoining drawings really intersect on that line?
2) Is it possible to restore lane markings that are required for advanced navigation and safe driving support but are not drawn in almost all expressway CAD drawings? (Lane markings exist on the drawings of national highways and hence there is no problem for them.)
3) How accurate are the coordinates of objects on a CAD drawing?

The reason lane markings are not drawn is that the contract of the painting of lane markings is assigned separately after a road construction work and thus lane markings do not exist on the drawings drawn just after a construction work.

In addressing above issues 1), 2) and 3), we have taken Kyushu Expressway as an example. The drawings between Yahata-Wakamiya Interchange and Kiyama Parking Area were investigated. The length of this stretch is about fifty kilometers and the number of drawings is fifty eight.

There remains an important issue related to Step 4:

4) Is it possible to combine adjoining drawings to prolong a road? And how accurate are the combined drawings?

Investigation of the point 4) is now underway and the result will be presented at another opportunity.

In the following section 3, the issue 1) mentioned above is addressed. In section 4, the issue 2) is addressed. Following these, in section 5, the issue 3) is described. Finally, conclusions and future perspectives are given.

3. CROSSING OF END POINTS OF SAME LINE SEGMENTS BETWEEN ADJOINING DRAWINGS

(1) METHODOLOGY

To check the quality of CAD drawings, we first investigated if the end points of two line segments that should intersect on the dividing line between adjoining drawings really intersect on that line. The types of separation of two end points can be broken down into three categories as shown in **Fig. 3**. The first category is the case where two end points overshoot and intersect at different point from the dividing line. The second category is the case where two end points cross the dividing line but do not intersect. And the last category is the case where two end points undershoot the dividing line.

The center line of an expressway, the inner and outer boundary of a carriageway and the edge of a road area were selected to measure the separation of end points on the di-

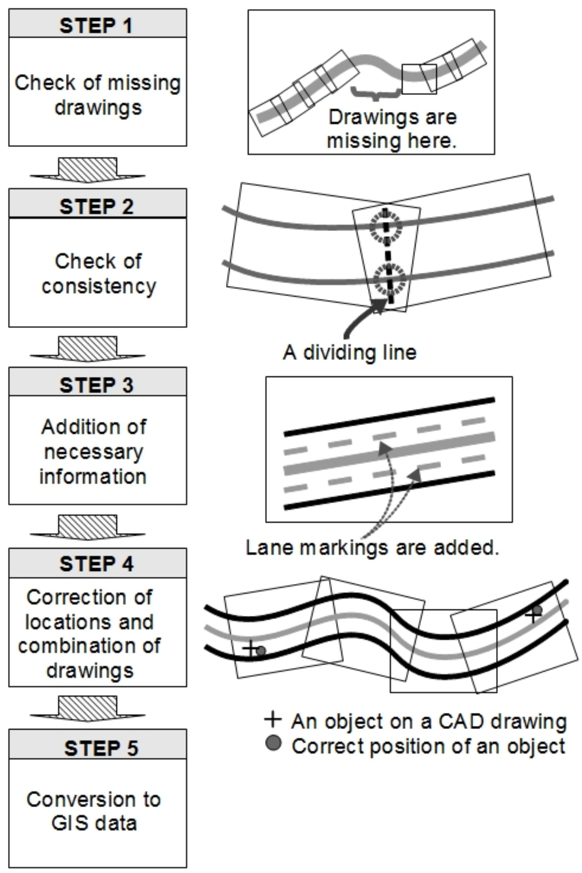


Fig. 2 Overall Process of Conversion of CAD Drawings to GIS Data

viding line of adjoining drawings. The distance between two end points of line segments was measured as shown in **Fig. 4** using a corresponding function of CAD software. An example of the separation of two end points on a dividing line is shown in **Fig. 5**.

(2) RESULTS AND DISCUSSION

Table 1 summarizes the result of the measurement and the accumulated ratios are shown, too. Please note that the difference of two end points of the line segments is the figure in an absolute size and not the distance measured on a drawing paper. Almost all the separations are small. In fact, ninety percent of separations are less than one millimeter except for the edge of road areas. However, in some cases that are rare, the separation is as large as one meter. If the separation is so large, then some remedy, which will be described below, should be applied. However, the reason why the separation of end points was made is not clear.

Approximately ninety percent of the separations of a center line are less than 0.001 mm and this ratio is higher than other types of lines by five to ten percent. On the other hand, the ratio of the separation greater than 100 mm is 1.7 percent. This figure is higher than other types of lines.

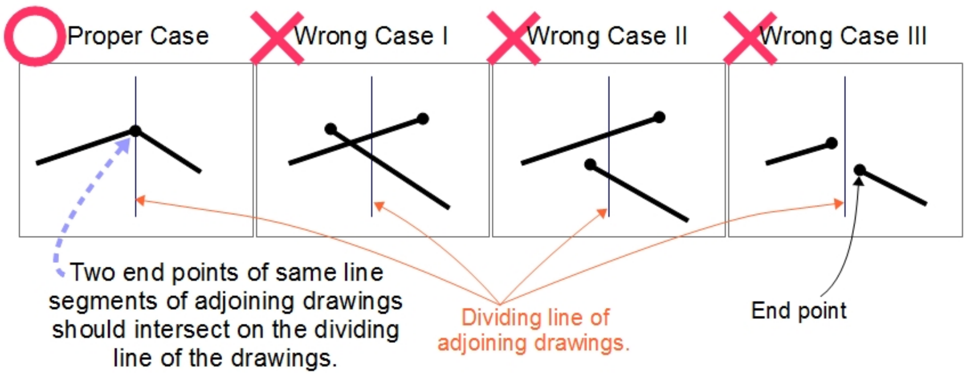


Fig. 3 Type of Separation of Two End Points

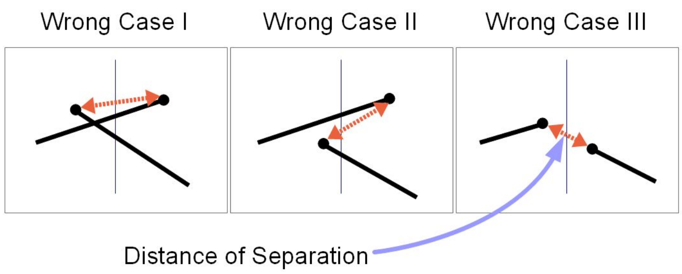
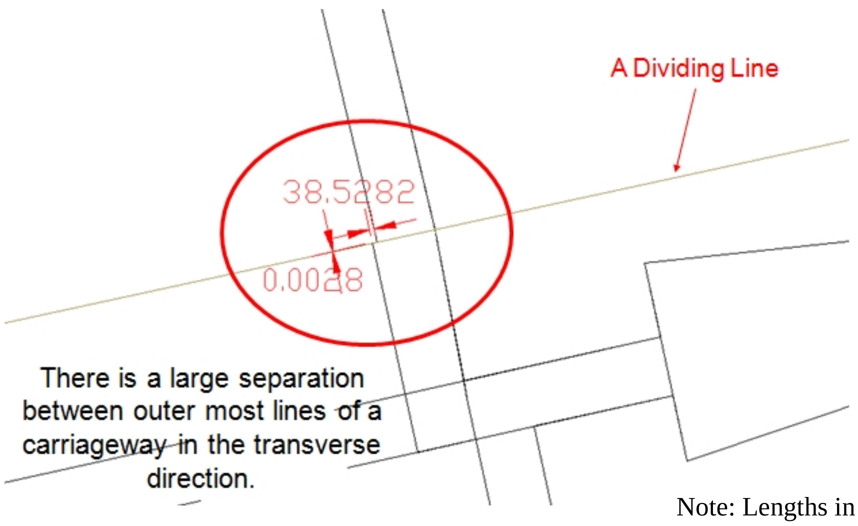


Fig. 4 Measurement of Separation



Note: Lengths in mm

Fig. 5 An Example of the Separation of End Points

Table 1 Measurement Result of the Separation of Two End Points

Separation in millimeter	Center Line of Expressway (58)	Inner Boundary of Carriageway (113)	Outer Boundary of Carriageway (115)	Edge of Road Area (113)
≦0.001	89.7 %	80.5 %	84.3 %	85.8 %
≦0.01	93.1 %	81.4 %	86.1 %	85.8 %
≦0.1	93.1 %	84.1 %	88.7 %	86.7 %
≦1	93.1 %	90.3 %	96.5 %	88.5 %
≦10	96.6 %	94.7 %	98.3 %	90.3 %
≦100	98.3 %	99.1 %	100.0 %	92.9 %
≦1000	100.0 %	100.0 %	100.0 %	100.0 %

Notes: Figures in parentheses are the number of points used for measurement.
Figures in percentage represent accumulated ratios.

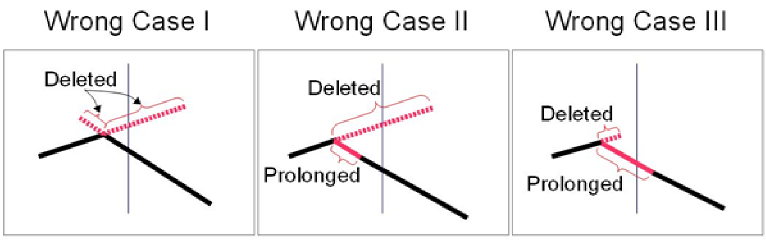


Fig. 6 Correction of Separation of Two End Points

It is worthwhile describing how to deal with the separation of end points. We have set two threshold values. One is 0.01 mm, and the other one is 1 mm. If the separation of two end points is less than 0.01 mm, then the two points are regarded as the same point in the CAD-GIS convertor mentioned above[13)]. In addition, if the separation is less than 1 mm, then the accuracy to the fourth decimal place can be maintained for longitude and latitude expressed in seconds. Therefore, if the separation is less than 1 mm, we have regarded two end points as the same point. If the separation is larger than 1 mm, then we have carried out an adjustment of the intersecting point of two end points by prolonging and/or deleting a part of line segment. The details are shown in **Fig. 6**.

If two end points overshoot and intersect at different point from the dividing line, then overshooting parts are deleted. If two end points cross the dividing line but do not intersect, then one line segment is prolonged to intersect the other one and the excessive part is deleted. Finally, if two end points undershoot the dividing line, then line segments are prolonged until they intersect and excessive part is deleted if necessary. In any case, the intersecting point is not located on the dividing line. The influence of these corrections will be investigated in the combination step of drawings.

4. RESTORATION OF LANE MARKINGS

(1) BACKGROUND

In most of the drawings of expressways, lane markings are not drawn. However, the information of lane markings is essential to sophisticated lane-level vehicle navigation and advanced drive assistance as mentioned above. To obtain this information, an aerial survey or measurement by a special vehicle with GPS and video cameras is required. In any case, this kind of measurement is expensive and time consuming.

One candidate that can substitute for these expensive measurement methods is the drawing parallel lines with the center line of an expressway and taking the resulting lines as lane makings. As far as expressways are concerned, this method looks promising partly because the widths of a lane, a shoulder and other cross-sectional components are standardized in Japan in accordance with the *category* and *class* of an expressway and partly because the radius of curvature of an expressway is so large that the widening of a lane is unnecessary. In addition, the standardized widths of an expressway are commonly used in Japan. This indicates that if we know the category and class of an expressway, it is easy to know the widths of lanes, shoulders and a median strip. Therefore, by drawing parallel lines with the center line of an expressway, it is possible to estimate the location of lane makings with high precision.

Here, the outline of *category* and *class* of an expressway is given. In Japan, roads are classified into four categories according to the location where they exist and their type[15]. Expressways in rural areas are category I and expressways in urban areas are category II. Highways in rural areas are category III and streets are category IV. The stretch of Kyushu Expressway from Yahata-Wakamiya Interchange to Kiyama Parking Area belongs to category I. Each category is further divided into classes according to traffic volume and the terrain. The stretch selected in this paper belongs to classes 1 and 2. Class 1 has greater traffic and is in a flatland and class 2 has smaller traffic.

However, the category and class of an expressway are not specified on CAD drawings. It was necessary to inquire the category and class of Kyushu Expressway of Japan Expressway Holding and Debt Repayment Agency to collect this information.

(2) METHODOLOGY

In designing the horizontal geometry plan of a road, the center line functions as a reference line. The lane markings are laid out based on the distance from the center line, which can be determined using the standardized widths. This procedure was followed in estimating the location of lane markings as shown in **Fig. 7**. The estimated location was compared with that obtained by a digital aerial triangular survey.

In a digital aerial triangular survey, an aircraft used for surveying is equipped with GPS and IMU (Inertial Measurement Unit). The position and the tilt of the aircraft are measured using these sensors. A digital aerial triangular survey has some advantages over the conventional aerial survey. One advantage is that the setting of reference points on the ground is no longer necessary. Consequently, there is no need to go into an expressway and the traffic flow will not be hampered. In addition, data processing is digitized. Therefore, the cost and time necessary for processing data can be diminished. These are the reasons we adopted a digital aerial triangular survey. In this study, the accuracy that is comparable with 1 to 1,000 scale maps was ensured for the aerial survey.

(3) RESULTS AND DISCUSSION

The minimum distance between the lane markings drawn using the procedure mentioned above and the digitized lane marking data obtained by the digital aerial triangular survey was measured. **Table 2** summarizes the results.

Nearly 90 % of offset lines were located within 0.25 m from the real world lane marking and the RMS error was 0.306 m. This result is encouraging because by simply drawing a parallel line we can estimate the location of lane markings with precision. Therefore, it is possible to estimate the location of lane markings at lower cost and for a shorter time. The width of a lane is approximately 3 m for highways and streets and 3.5 m for expressways according to the specification of *Road Alignment Ordinance*[15]. On the other hand, the width of a vehicle is approximately 1.7 m

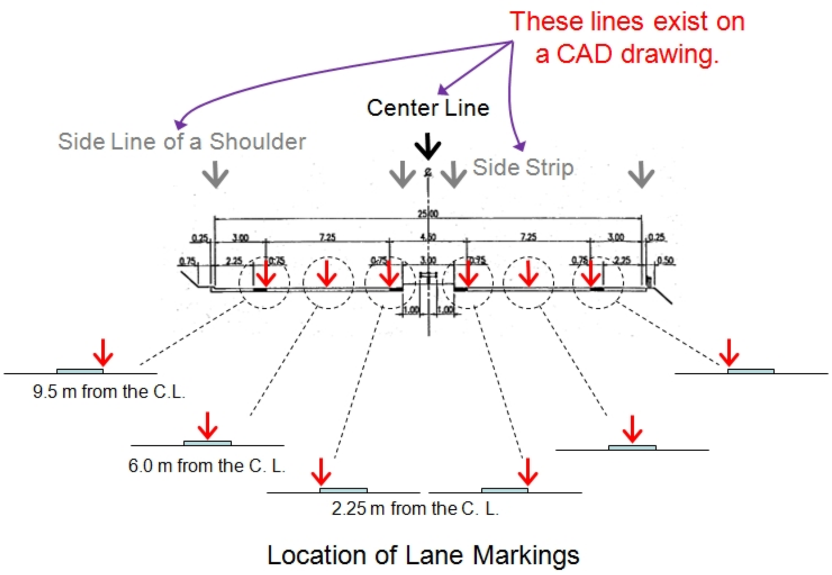


Fig. 7 Restoration of Lane Markings

for passenger vehicles and 2.5 m for trucks and buses. If vehicles are assumed to be driven at the center of a lane, then the lateral margin between a vehicle and the edge of a lane is above 0.5 m as far as passenger cars are concerned. However, if a truck or a bus is driven at the center of the lane with three meters in width, the lateral margin is only 0.25 m. This calculation indicates that the difference of 0.25 m is presumably the maximum value that can be accepted.

In closing this section, it is necessary to say that there is a limitation of the method proposed here to restore lane markings. This procedure may not be applicable to an interchange where the geometry of an expressway is complicated and standardized specification of widths is not relevant there. The restoration of lane markings in these areas remains to be solved.

5. ACCURACY OF THE LOCATION OF OBJECTS ON CAD DRAWINGS

(1) METHODOLOGY

In order to check the location accuracy of objects on CAD drawings, we have picked out some objects from each drawing. The selected objects should be identified both on a drawing and on an aerial photo. The following objects were selected and their location was measured using a digital aerial triangular survey:

- Boundary of a carriageway, in particular the nose end of an traffic island and the point where the road width changes;
- Structures such as an elevated bridge, a culvert, and a tunnel; and
- Milestones that are placed every 100 m along an expressway.

Approximately sixteen objects were chosen from each drawing on average.

Table 2 Difference of Lane Markings

Difference in meter	Number of Points	Accumulated Ratio
≦0.25	120	89.6 %
≦0.70	10	97.0 %
≦1.70	4	100.0 %
≦3.50	0	100.0 %
＞3.50	0	100.0 %
RMS Error	0.306	---

Note: *Defference* is measured as the minimum distance between the restored lane marking and that obtained by the digital aerial survey.

The coordinates of objects measured on a CAD drawing were compared with the absolute coordinates obtained by a digital aerial triangular survey that was assumed to be the true position. The difference of these two coordinates was measured and the result is summarized in **Table 3**. Figures in this table represent an accumulated ratio. The milestones were difficult to identify on a aerial photo and hence the number of measuring points is small.

Among the objects chosen here, elevated bridges have the advantage over other objects. That is, it is unnecessary to go into an expressway in obtaining the coordinates of the elevated bridges. In this study, an aerial survey was adopted and hence this advantage was not enjoyed. Nevertheless, in pursuing a less expensive method, the utilization of elevated bridges looks promising.

(2) RESULTS AND DISCUSSION

The location accuracy of bridges is good because 85 % of bridges have the difference less than 1.7 m and the RMS error is the minimum among the objects. This figure (1.7 m) is equivalent to the accuracy of a map with the scale of 1 to 2,500. On the contrary, the location accuracy of tunnels and milestones is not so good. The RMS error of milestones is the worst. Therefore, this result indicates that objects drawn on a CAD drawing do not have comparable location accuracy with each other.

Table 3 Results of the Assessment of Location Accuracy of Objects on CAD Drawings

Distance Between Two Points in meter	Edge of Roadway	Structures				Milestones	All Objects
		Bridges	Elevated Bridges	Culverts	Tunnels		
≦0.25	3.8 %	4.7 %	2.7 %	5.6 %	0.0 %	4.6 %	6.3 %
≦0.70	30.2 %	35.4 %	10.8 %	30.6 %	0.0 %	13.6 %	35.2 %
≦1.70	73.6 %	85.4 %	62.2 %	72.2 %	50.0 %	36.4 %	80.9 %
≦3.50	94.3 %	98.6 %	94.6 %	91.7 %	75.0 %	72.7 %	96.6 %
＞3.50	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %	100.0 %
RMS Error	1.63	1.30	1.94	1.85	2.35	2.86	1.63

Note: Figures in percentage represent accumulated ratios.

The difference of the location accuracy among objects may be caused by the transient characteristic of some objects. For example, milestones are easily damaged by an auto crash. If they are damaged, they will be rebuilt. However, they may not be rebuilt on the same position as before. This change of the position may not be reflected on the CAD drawing. In addition to this, a minor alteration may be done to the original plan during a construction work and it is unlikely to be reflected on a drawing.

We have checked the location of end points of elevated bridges identified on site against that drawn on CAD drawings. One example is shown in **Fig. 8** where a CAD drawing is superimposed on an orthophotograph. In this case, the difference was as large as 0.43 meter. This result indicates that the objects on a CAD drawing be chosen carefully.

A similar investigation of location accuracy was made in the Comprehensive Technology Development Project entitled 'Development of national surveillance system to reduce damages of disasters[9]'. They used two kinds of drawings of national highways, one for road improvement works with the scale of 1 to 500 and the other for road maintenance works with the scale of 1 to 1,000. They measured the coordinates of sidewalks, planting and bridges by network RTK-GPS and compared them with the coordinates of corresponding objects drawn on CAD drawings. It was found that the RMS error for drawings of improvement works is more than four meters while the RMS error for drawings of maintenance works is the submeter order. The results obtained here are just between them.

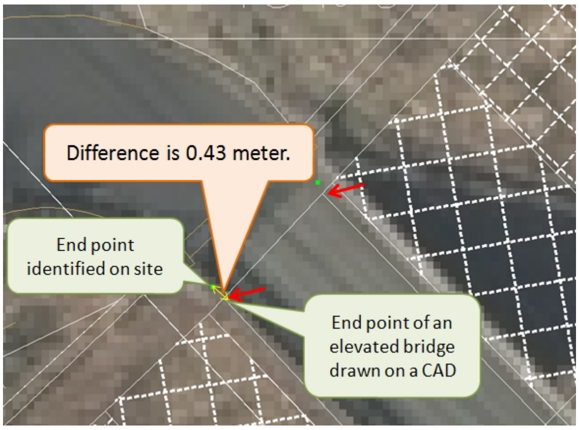


Fig. 8 Comparison of the location of an end point of an elevated bridge

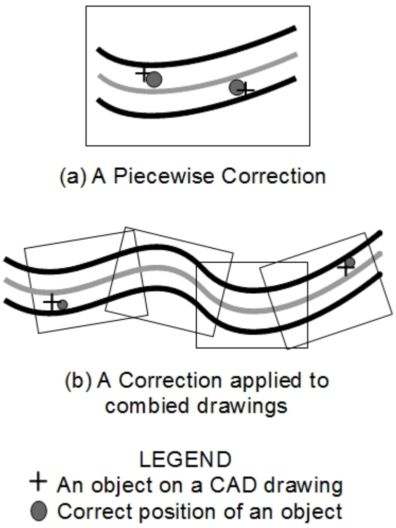


Fig. 9 Correction of Location Errors

In converting CAD drawings to GIS, it is necessary to rectify location errors that exist on CAD drawings. The correction of location errors in each drawing can be realized by transforming a CAD drawing by rotation, scaling and translation. The Helmert transformation, a special case of the Affine transformation, can realize these transformations and is more preferable because it is distortion free. This is a *piecewise* correction (**Fig. 9 (a)**) because it is applied to each drawing one by one. In a piecewise correction, two reference points used for location correction are necessary in each drawing. In contrast to this, transformation can be applied to *combined* drawings (**Fig. 9 (b)**). In this case, two reference points are required on the *combined* drawings. Hence, the flexibility of correction is greater. In addition, the dividing line between adjoining drawings is automatically transformed in this case, and thus the combination of drawings can be done more easily.

The accuracy of the combined drawings is under study at present and the result will be shown in the near future.

6. CONCLUSIONS

This paper is the first step to investigate the possibility of the conversion of CAD drawings of the horizontal geometry plan of expressways to GIS data. If this conversion is realized, then it is possible to provide users with latest digital road maps with high frequency.

We have examined the quality of CAD drawings from two points of view. First, we checked whether end points of same line segments that should intersect on the dividing line really intersect on that line. It was found that the separations of two end points are small and that ninety percent of separations are less than one millimeter in an absolute size. However, the separation is as large as one meter in some rare cases. If the separation is larger than 1 mm, we carried out an adjustment of the intersecting point of two line segments by prolonging and/or deleting a part of them.

In addition to this, we have checked the location accuracy of objects on the CAD drawings. The coordinates of objects measured on a CAD drawing were compared with the absolute coordinates obtained by a digital aerial triangular survey. It was found that the location accuracy of bridges is good and 85 % of bridges have the difference less than 1.7 m. However, the location accuracy of tunnels and milestones is not so good. In addition, it was found that CAD drawings do not necessarily reflect the results of construction works.

We have proposed two ways of correcting this difference. One is to apply Helmert transformation to each drawing and make the difference as small as possible. The other one is to apply Helmert transformation to combined drawings. In the latter case, only two reference points are required on combined drawings and thus it has more flexibility than a piecewise correction, in which case two reference points are necessary on each drawing. However, it is improbable that there exist two reference points on each drawing.

We also tried to restore the location of lane markings because in most of the drawings of expressways lane markings are not drawn. Standardized widths are used for the layout of an expressway in Japan, and hence by drawing parallel lines with the center line of an expressway the location of lane makings can be estimated easily. It was found that the RMS error of this estimation is 0.306 m. This figure is satisfactory at least for lane level navigation. In addition, this drawing-an-offset technique is less expensive and leads to time saving.

The remaining issue is the combination of adjoining CAD drawings to obtain prolonged GIS data of an expressway.

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