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Housing Estate Developments and Earthquake Hazards

- Some recent cases in Japan -

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-일본에서의 최근 사례를 중심으로-

Abstract : Housing estates widely spread on the hills of urban fringe area in many Japanese cities These housing estates were developed during the rapid urbanization phase since the 1950s, by transforming the landform by cutting and filling The damages caused by the recent earthquakes in Japan concentrated on such areas.

Most of the heavily affected houses were located on the boundary between cut and fill or on the filled sites. There are strong relationships between damage occurrence and land conditions associated with artifical land transformation.

Key Words : Land transformation, Land condition, Earthquake hazard, Urbanization, GIS and Japan

요약 : 1950년대 이후 일본의 많은 도시지역에서는 구릉지를 중심으로 한 택지개발이 활발히 이루어져왔고, 그 결과 이 지역의 지형은 절개와 매립에 의해서 많은 변화를 겪게 되었다. 그런데, 1978년, 1993년, 1995년 등에 발생한 지진에 의해 이러한 택지에 건설된 주택의 상당한 수가 피해를 입었다. 지진의 피해를 특히 많이 받은 주택들의 대부분은 절개지와 매립지 사이에 위치한 것들이었다 이를 통해 지형 및 그 변형에 관련된 토지의 상태와 지진에 의한 주택의 피해정도 사이에는 상관관계가 성립한다는 것이 입증되었다. 심포지움에서, 연구자는 GIS를 이용한 분석법을 활용하여 일련의 사례 연구들을 제시할 것이다.

주요어 토지변형, 토지상태, 지진 위험, 도시화, 지리정보체계와 일본

1. Earthquake hazards on artificially transformed hills: the experience from the Miyagi-ken-oki Earthquake 1978

The Miyagi-ken-oki Earthquake 1978(Ms = 7.4) hit Sendai City, with a million population and much of housing estates built on the surrounding hills. A close relationship was found between the types of damage to houses and land conditions of their sites(Fig. 1). Whilst the CBD and the residential areas on the terraces were only slightly affected, the heavier damages concentrated on the houses and buildings on the alluvial plain, and on housing estates on the artificially transformed hills. The focus of this paper is on the latter.

Figure 2 is an example of the affected areas on the transformed hills, showing land transformation and earthquake damages in Nankodai, on the northeast of Sendai. It is clearly demonstrates that severely damaged houses concentrate on the cut/fill boundary.

The type of damages to houses on artificially transformed hills differs by the scale and/or the degree of landform transformation(Figure 3). One type is the estate on slight land transformation

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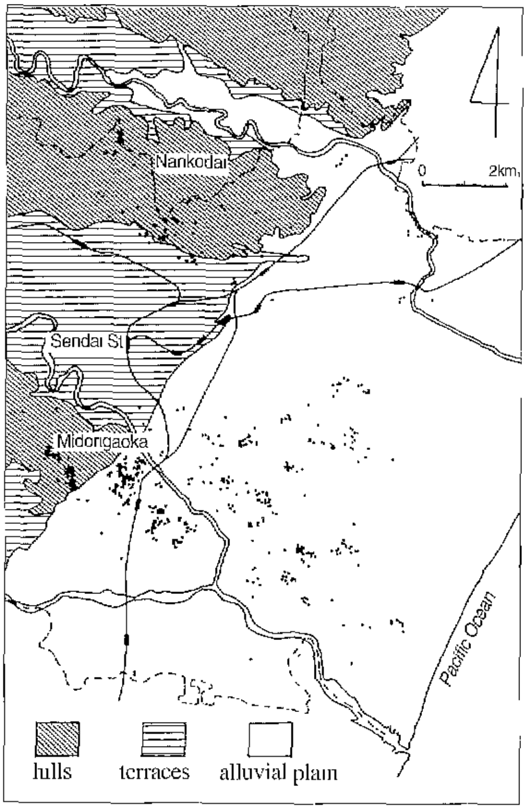

Figure 1. *The distribution of houses totally damaged by the Miyagi-ken-oki Earthquake in 1978, and landform classification in Sendai City (Murayama, 1994) Dots in the figure represent totally damaged houses.*

where almost every housing lot has small cut and fill with walls retaining the cliff(Type A in Figure 3). The damages mostly occur on retaining walls causing cracks, and at times, retaining walls collapse and houses slide or topple. The damage at Midorigaoka on the transformed hill southwest of the CBD, is the typical case for this type of damage.

The other is the estate on a massively transformed ground, where several valleys are filled with soils from the cut ridges(Type B in Figure 3). On such places, subsidence may occur on filled areas, in addition to cracks at the boundary between cuts and fills. Houses could be damaged with fissured and/or tilted basement. The damage of the houses showed in Figure 2 is the case of this *type B' in Figure 3 is showing the vertical section* of the Type B transformation. Of this dimension, the edge of the fill could be pushed out or would sometimes collapse.

The vulnerability of artificially transformed lands to earthquake reappeared at subsequent earthquakes of Kushiro-oki 1993 and Hanshin-Awaji(Kobe) 1995(Murayama and Sugano, 1994; Murayama et al., 1995).

2. Measuring the damage probability of houses on artificially transformed hills upon Earthquake: the case of Kushiro-oki Earthquake 1993

The recent developments in GIS technology enabled a quantitative analysis of landforms and distribution(Figure 4) The relationship between artificial land transformation and damages caused by the Kushiro-oki Earthquake 1993 are examined.

1) The data

The distribution of affected houses with their level of damages categorized into 5(totally, severely, partially and slightly damaged and no damage) was obtained from the data collected by Kushiro City.

The topographic map of Kushiro City 1956 and 1987(scale 1:3,000 and 1:2,500, respectively) were used as representing the surfaces before and after major artificial land transformation. The contour lines of these two maps were digitized, and then the two surfaces were modeled within GIS. The artificial cuts, fills and cut/fill boundaries were extracted by subtracting the present surface from the original surface. The following attributes for each housing lot were calculated as land condition indices

(1) whether the lot locates on cut, fill or boundary;
The boundary zone is defined as within 6 meters from the cut/fill boundary.

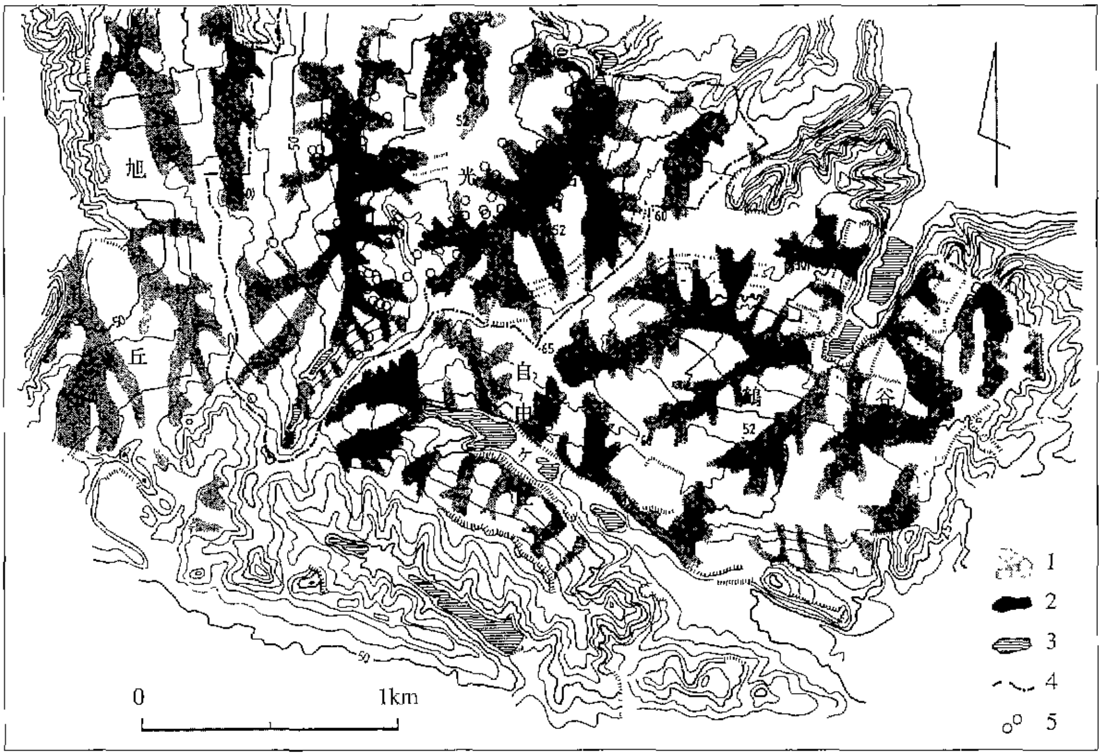

Figure 2. Land transformation and earthquake damages in Nankodai(Abe and Murayama, 1982)
1 : filled area, 2 : filled pond, 3 : pond, 4 : Nankodai(surveyed area), 5 : severely affected houses
Contour lines and numbers show the altitudes in 1970 after transformation, figures in brackets are the elevation before modification.

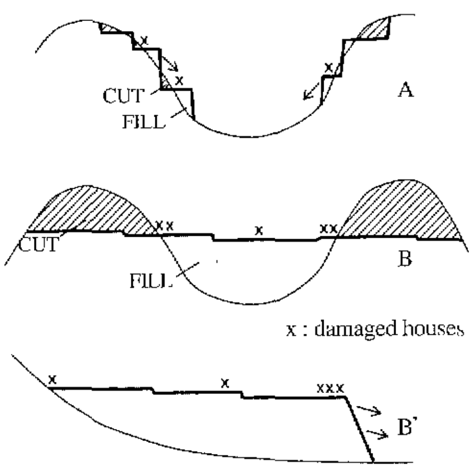

Figure 3. Schematic diagram of land transformation and location of risks(Murayama, 1980)

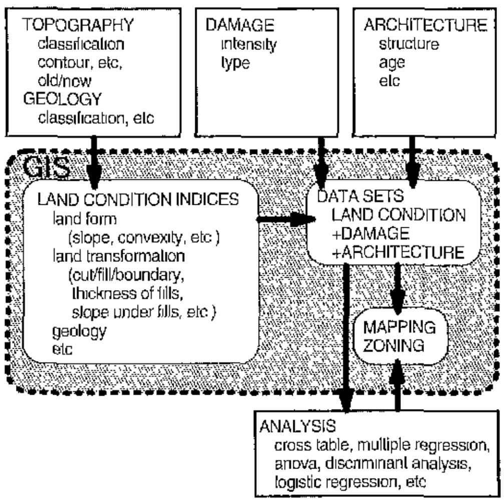

Figure 4. Framework for GIS assisted analysis of the damage to built environment by earthquake

(2) distance from the cut-fill boundary
(3) thickness of fill
(4) slope of the original surface under the fill
(5) slope of the present surface
(6) concavity/convexity index of the present surface;

This was calculated by subtracting the elevation of the area from the average elevation of the surrounding area. The sites having large negative values indicate convex areas, which are mostly on the brink of the cliffs.

These six indices on land condition were added as attributes to affected and non-affected houses.

2) The Analysis

Results from cross tabular analyses in Figure 5 demonstrate that, (1) houses on the filled area and on the cut-fill boundary are more prone to damage in both quantity and intensity; (2) positive relationship exist between frequency of damage and thickness of fill; (3) heavy damages concentrate on lots where the slope of original surface is steep; and (4) lots with high convexity such as those on the brink of cliffs, are more prone to damage. No apparent effect was found for the slope of the present surface.

A series of discriminant analyses was pursued to examine how well the level of damages can be predicted by the land condition indices. The independent variables were (a) distance from the cut-fill boundary; (b) thickness of fill; (c) slope of the original surface under fill; and (d) concavity/convexity, whereas the dependant categories were the original 5 levels of damage.

After several trials, sound prediction into two aggregate categories "totally + severely" and

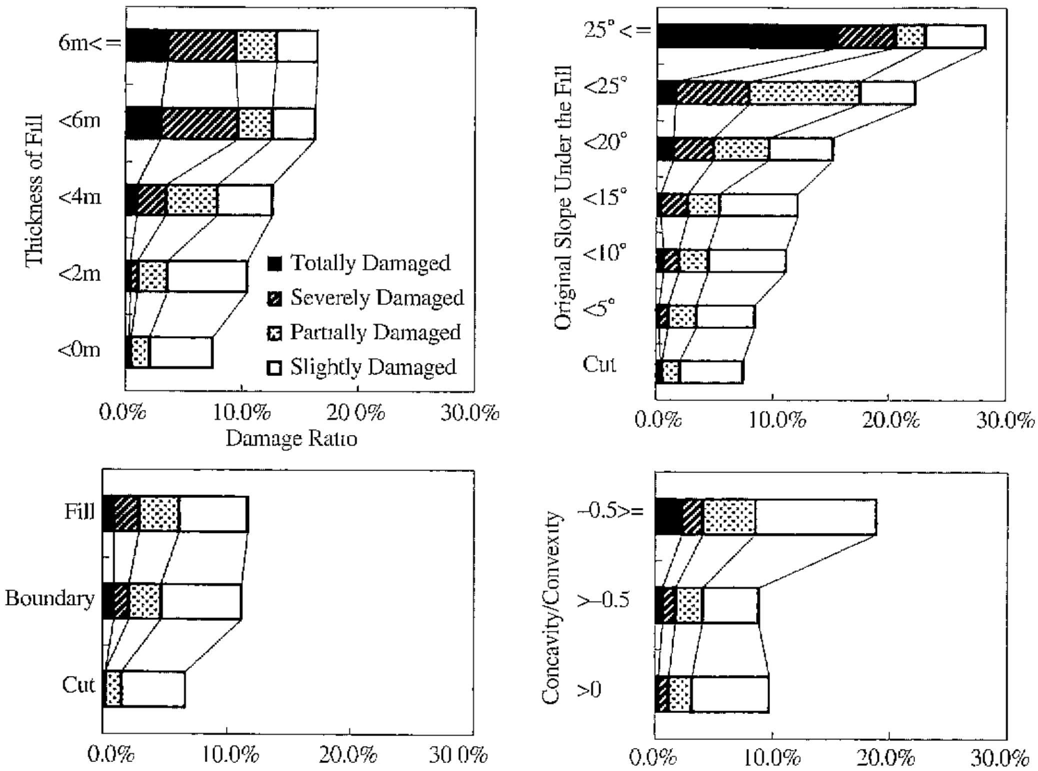

Figure 5. Land condition indices and damage intensity

Table 1. Classification results

		PREDICTED GROUP		TOTAL
		NO DAMAGE ETC.	TOTALLY+SEVERELY	
ACTUAL GROUP	NO DAMAGE ETC.	2232	491	2723
	TOTALLY+SEVERELY	14	35	49
	NO DAMAGE ETC.	82.0%	18.0%	
	TOTALLY+SEVERELY	28.6%	71.4%	

81.8% of original grouped cases correctly classified

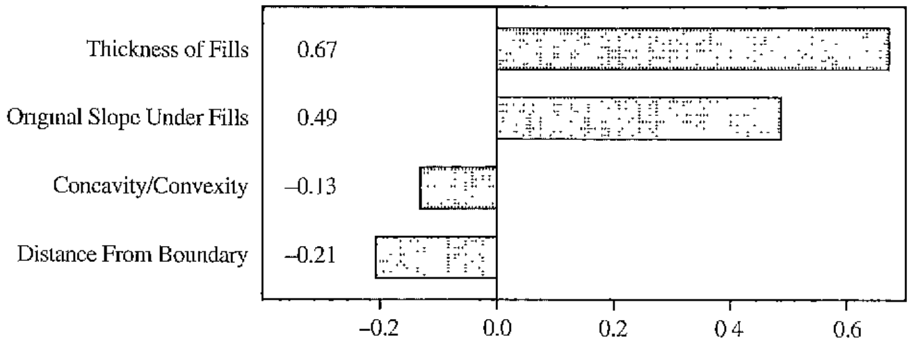

Figure 6. Standardized discriminant coefficients

"partially + slightly + no damage" was obtained. The contingency table shows how correct these aggregate categories were predicted using only the land condition indices, with overall prediction ratio of 82%(Table 1). The standardized discriminant function coefficients show that the thickness of fill and the slope of original surface under the fill are the main determinants to the intensity of damage(Figure 6).

3. Concluding remarks

The experiences from the recent seismic disasters in Japan have convinced that houses on artificially transformed hills are more prone to damage. The discriminant analysis revealed that a few indices on land condition could sufficiently predict the degree of damage, despite apparent lack of necessary variables such as geological conditions and architectural structures of houses. Further more, the analysis revealed that it is the structure beneath artificially transformed lands that mainly determines the probability being affected for heavier damages. These firmly suggest that ground failure is the main cause of the damage to houses and buildings.

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