# *Development of web-based slope stability evaluation system (SSE-web)*

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**Abstract:** For better evaluation of hazardous area affected by the slope failures as well as landslides, the web-based Slope Stability Evaluation model (SSE-web) has been constructed. In the SSE-web, the relationship between the "past slope failures" and the "causal factors (i.e., satellite remote sensing data, geographical information)" are constructed. The SSE-web consists of the following systems; i) Pre-processing system, ii)Analysis system, iii)Post-processing system, and iv)Information providing and management system. The functions for making the causal factors belong to the pre-processing system. Through the analysis system, the factor analysis could be carried out on the slope stability evaluation. The post-processing system supports the editorial works on the slope stability evaluation maps as well as the analysis results. Furthermore, the post-processing system assumes a role to provide and manage those data sets. The system designs on the SSE-web might be a good guide for constructing the related system of spatial-data integration and analysis under the internet-environment.

***Keywords*** : *slope stability evaluation, network environment, satellite remotely sensed data, geographical information, quantification method, spatial data integration and analysis,*

## 1. Introduction

Research has been made since old times on technologies for foreseeing the "time, position and scale of occurrence" of slope failure, and utilization of the results of research is strongly requested. For the purpose of grasping the "position" and the "scale" of slope failure in advance among those 3 requirements of prediction, we developed a SSE (Slope Stability Evaluation) model using satellite data and geographical information) capable of utilizing various types of geographical information such as topography, surface geology, soil, etc. and satellite remote sensing data (all those factors are named "causal factors") by fusing them[1], and we are also accumulating a lot of achievements of application to practical work, in parallel with implementation of basic studies such as proposal of various types of evaluation algorithm[2),3)], verification of evaluation accuracy[4),5)], etc.

The SSE model, which operates under UNIX environments and Windows environments, was designed and developed as "stand alone" system in either case. However, as accumulation of the cases of application progressed, there arose a request for operation of SSE model under Internet environments, including measures for adaptation to sharing & management of input information and results of processing, etc. This is a request which arose inevitably from the side of users in line with spectacular improvement of network environments during the past few years.

SSE model is based on the method of multivariate analysis the nucleus of which is the quantification theory. There are a lot of subjects to be studied for operating a SSE model under the Internet environments, including selection of criteria of discrimination (past landslide occurrences, etc.: which are called "training data"), preparation of causal factors and their setting into data, various analyses regarding slope stability evaluation, sharing & management of files, design of user interface (GUI: Graphical User Interface), etc.

With such situation as background, we started, in the present research and development, design and development of a slope stability evaluation system (SSE-Web: Web-based Slope Stability Evaluation system) which operates under the Internet environments, for the purpose of supporting slope stability evaluation over a wide area.

The slope stability evaluation system of the present study is intended to extract points having soil properties similar to those at the points of past landslide occurrences, with the causal factors as explanatory variates. Predicting the "time of occurrence of failure" of slope (including building of model) individually over a wide area is one of difficult problems. A study attempting to predict the time of occurrence of failure, made by installing measuring instruments such as inclinometer, etc., on some specific slope which is known to be dangerous in advance, is a prediction of failure of "point", and the question of tie-up with stability evaluation as "face" of the present study will be left as a subject to be studied in the future.

## 2. Purpose of research

The following 3 points are the purposes of the present research and development:

(1) Clarify the needs and significance of development of slope stability evaluation system (SSE-Web) operating under the Internet environments, and then study basic requirements to be satisfied by SSE-Web.

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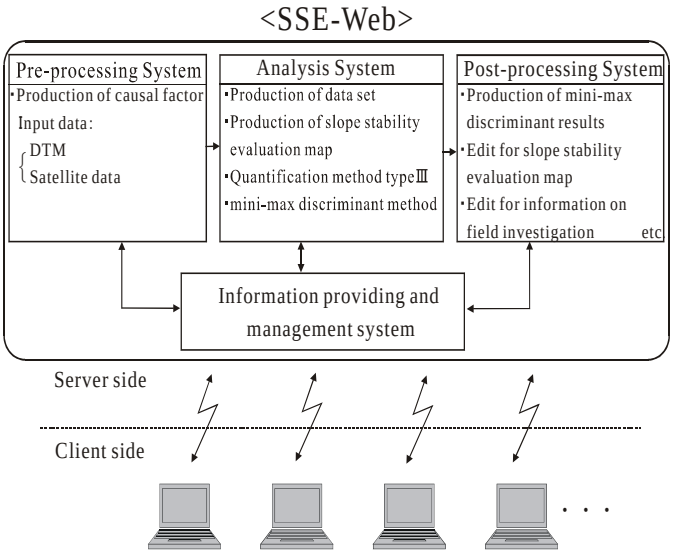



**Fig.1** Sub-systems of SSE-Web.

(2) Study the flow of a series of processing and input/output relations of information regarding slope stability evaluation, through analysis of the respective subsystems, i.e. "pre-processing," "analysis," "post-processing" and "information supply & management" systems. We will also study the structure of data set to be shared by the subsystems, and promote design and development of the element functions to be provided on the system.

(3) Study "in-picture design (including control panel design)" and "picture transition design"(link relation between pictures) corresponding to those element functions, and set them into SSE-Web. Convert the information handled on SSE-Web into data set in units of geographical areas, and build a system capable of continuously sharing and managing those data sets by means of an information supply & management system.

## 3. Features of research and development

Ten and several years have passed since a slope stability model was made public in 1990[1]. During this period, we promoted system development, in parallel with studies based on the theory of accuracy[2)-5)], to enable the SSE model workable under the UNIX environments[6)] and the Windows environments[7)]. Those developments, which were made independently of each other at different times, in correspondence to changes of OS environments, were different form each other in control structure of data set and operating method of the system. Therefore, it is also a fact that the frequency of use of SSE model operating under the Windows environments, which came to be widely accepted, has become higher naturally. Moreover, as achievements of application of SSE model increased, accumulation of data sets progressed, producing problems of sharing and management of the respective data sets workable under the UNIX environments and the Windows environments.

In response to such problems arising in the system operation, the needs emerged for construction of a new slope stability evaluation system workable under the Internet environments.

There are many problems to be studied, for developing and operating a highly specialized technical processing & analysis system under the Internet environments, unlike that of office work processing duties (fixed form). Also in this research and development, we encountered unexpected problems in the design and development of GUI, such as preparation of causal factors and conversion thereof into data set, as well as various kinds of analyzing functions, etc. The features of the developed SSE-Web may be summarized in the following 3 points:

**a) Securing uniformity of operation**

Engineers having utilized any system dealing with processing & analysis of various types of spatial information have certainly experienced a need of reviewing the manual, in spite of operations to which they are well accustomed, for some unexpected modification of GUI, etc. accompanying upgrading of version of the system. Moreover, although there are many studies and books regarding the theory of GUI design under Windows environments[8)], discussions regarding "picture transition design" and "in-picture design" in processing & analysis system of highly specialized technical field are surprisingly rare.

Under such circumstances, we first classified the SSE-Web system into 4 subsystems of "pre-processing," "analysis," "post-processing," and "information supply & management" systems as shown in **Fig.1**, and proceeded with "picture transition design" and "in-picture design" in parallel with each other, to conform to a series of processing procedures relating to slope stability evaluation.

Furthermore, we intended to enable to execute the respective processing steps through a single type of control panel, to avoid stratification of menu pictures (hereinafter called control panel )in the execution of processing steps. The internal construction of this control panel was unified with only 4 types of component element or (i) selection of processing method, (ii) specification of input of processing parameters, (iii) specification of input file, and (iv) specification of output file, and reflected in the "in-picture design." This not only sharply improved the efficiency of system development but also made operation training at the time of introduction of the system almost unnecessary, raising the processing efficiency in the execution of practical work.

As described above, SSE-Web is realized as a "guided linkage system" having "processing guidance and system linkage" as requirements.

**b) Improvement of efficiency of system operation & management**

Distinction is made between "fixed form processing" and

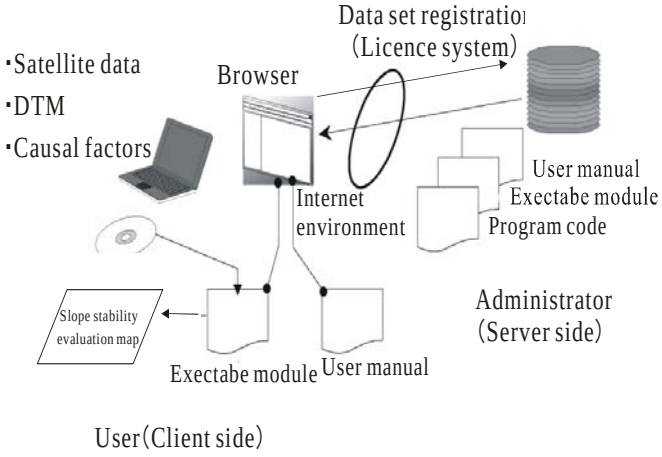



**Fig.2** Operational environment of SSE-Web.

"non-fixed form processing," as a viewpoint of design and development of SSE-Web. Flexible design is required in such a way to make the operation of fixed form processing section without hardly any changes but make use of image processing software for general use, etc. as required, in addition to simple expansion of functions, in the non-fixed form processing section.

For example, "pre-processing system" dealing with the processing of preparing causal factors corresponds to the fixed form processing section, and there is hardly any need of modification or expansion of the pre-processing function. There is no need of any responsive measures to make on the part of the user for adaptation to installation or change of GUI due to upgrading of version of the processing function, improving efficiency in the operation and management of the system. This is a design feature of SSE-Web and, in other words, it is another significance of developing SSE-Web under the Internet environments.

**c) Realization of guided linkage system**

In implementing slope stability evaluation, we deal with a variety of information such as causal factors, training data serving as standard of discrimination, slope stability evaluation map, results of analysis of statistics, field survey information (still picture, moving picture, survey ledger), reporting documents, etc. In SSE-Web, those pieces of information are handled as sets in "units of geographical area and JOB" as sets each of which is called "data set". In the present study, we also built an information supply & management system capable of operating and managing this data set. This SSE-Web can therefore not only support continued analysis but also contribute to supply & management of information. Utility of this system has been confirmed through practical use, not only as slope stability evaluation supporting system but also as guided linkage system operating under the Internet environments.

## 4. Design of SSE-Web

### 4.1 Operating environments of SSE-Web

As shown in **Fig.1**, SSE-Web operates on a personal computer connected to the Internet. There is no need of preparing any special operating environments, and the system with no limitation of time and place is constantly available for use. **Fig.2** indicates the operating environments of SSE-Web.

(i) System users (client side)

The operating form of this system consists in downloading a Java applet to the client side (Java SDK 1.4 ~), for performing processing and analysis at the user's hand. As precondition, the user must purchase and own the data forming the subject of processing (satellite data) and DTM (Digital Terrain Model).

(ii) System controller (server side)

The system controller, on his part, manages execution form file and program source and, after concluding an agreement on the use of the system with the user, distributes a password to the user and establishes an organizational setup for operation & management of the system. In addition, the system controller also receives and registers data set approved by the user, and performs transmission and management of information with an information supply & management system.

### 4.2 System construction

SSE-Web is composed of 4 subsystems, i.e. "pre-processing," "post-processing" and "information supply & management." Those systems are arranged in **Fig. 3** together with the flow of processing, so that the relations of linkage among them may be grasped at a glance. The information deriving from the pre-processing, analysis, and post-processing can be shared and managed at the information supply & management system.

### 4.3 Data set structure

**Fig.4** indicates the basic structure of data set. SSE-Web deals with a variety of processing & analysis information such as causal factors, training data (discrimination standards), slope stability evaluation map, field survey ledger, reporting documents, etc. including intermediate files. Those pieces of information are arranged into "data set" in units of JOB (processing units by geographical areas), and managed "in units of prefectures and municipalities." The data set structure indicated in **Fig. 4** is shared by the information supply & management system, enabling efficient and continuous management and operation of the data set.

### 4.4 Categories of processing

These authors realized efficient and continuous management and operation of software resources, by defining "categories

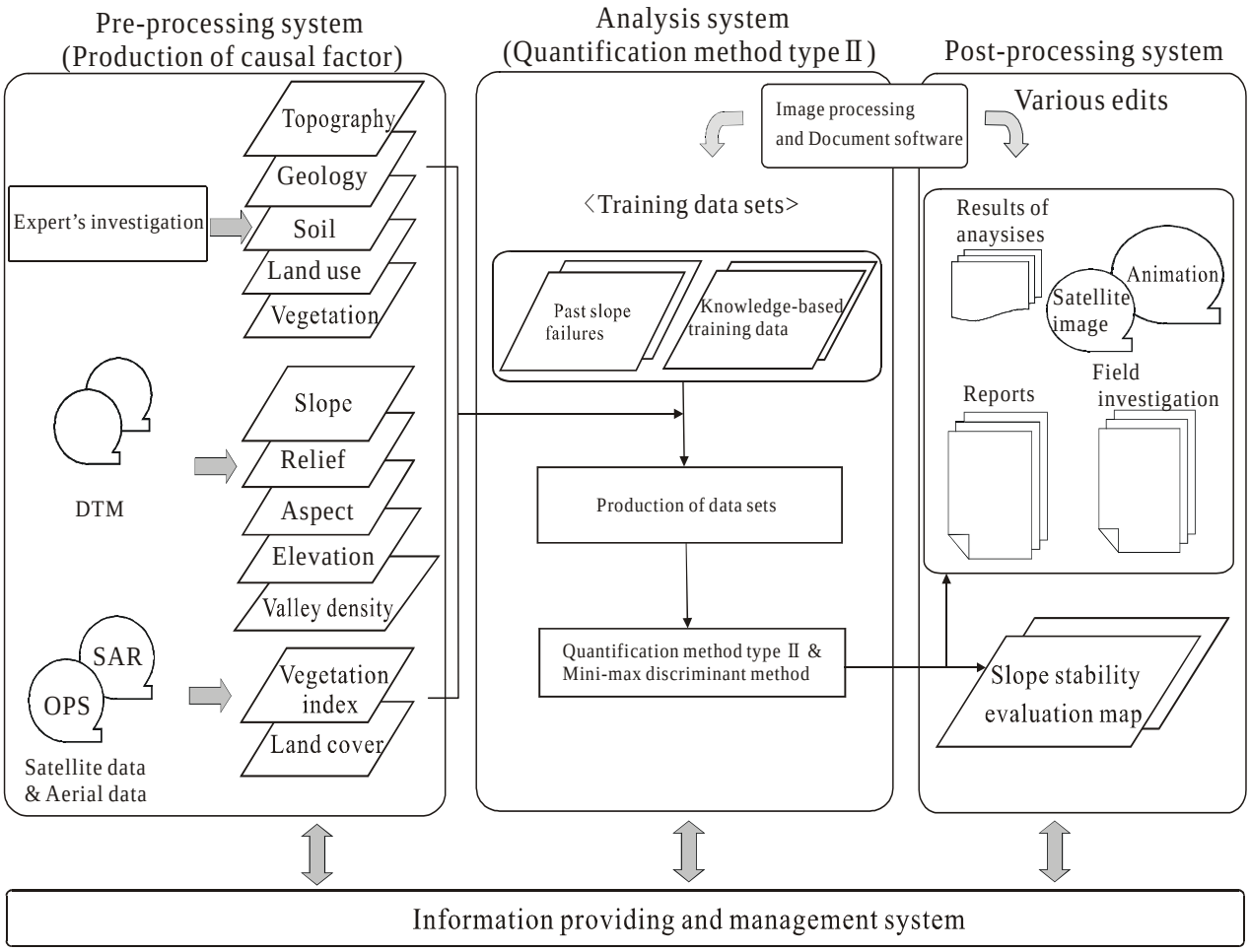



**Fig.3** Analysis procedures in SSE-Web.

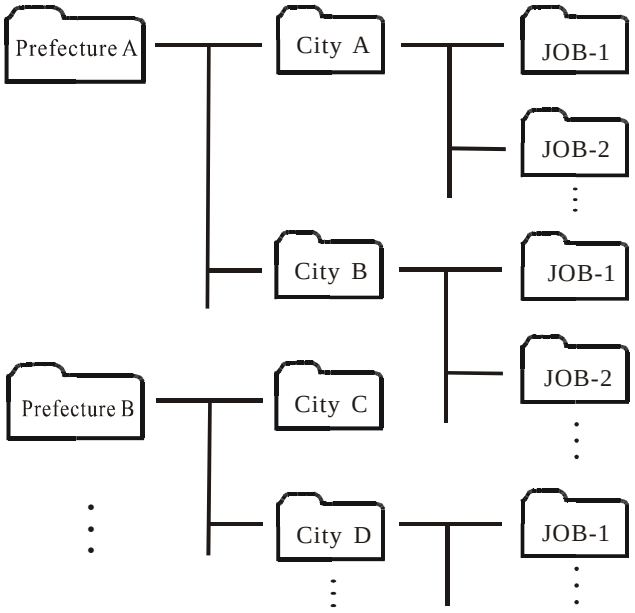



**Fig.4** Structure of data sets.

**Table 1** Functions of SSE-Web.

| | Processing | | Processing tipe-1 | Processing type-2 |
|---|---|---|---|---|
| Pre-processing system | Geometric distortion correction 1 (Calculation of coefficent of affine transformation) | | | ○ |
| | Geometric distortion correction 2 (Resampling) | | | ○ |
| | For DTM | Elevation | | ○ |
| | | Slope | | ○ |
| | | Relief | | ○ |
| | | Aspect | ○ | |
| | | Valley density | ○ | |
| | For Satellite data | Vegetation index | ○ | |
| | | Making training data sets (For land cover classification map) | ○ | |
| | | Making land cover classification map | | ○ |
| Analysis system | Making data set | | | ○ |
| | Slope stability evaluation (Quantification method type Ⅱ, Mini-max discriminant method) | | | ○ |

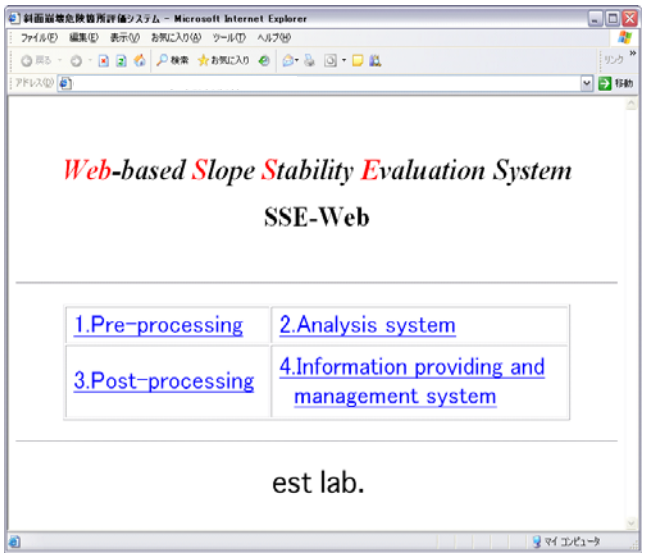



**Fig.5** Main menu of SSE-Web.

of processing construction", through achievements of development of a large volume of software handling image processing and analysis of satellite data under the UNIX environments[9].

This conception was retained also for the functional groups of SSE-Web operating under the Internet environments, and we promoted development of software and construction of library for it, according to 2 different types of "category of processing construction" as shown on **Table 1**. This category of processing construction contributes as frame for management of library and expansion of functions.

**a) Processing-1**

Programs for outputting the results of processing by simply specifying input data, without requiring any processing parameter, belong to "Processing construction 1." For example, preparation of NVI (Normalized Vegetation Index) as causal factor, slope aspect map, etc. falls under this category. In SSE-Web, several different types of NVI can be selected and/or prepared.

**b) Processing-2**

Processing programs requiring preparation of "control file (execution control file)" before executing image processing & analysis, in addition to the processing of "Processing construction 1" belong to "Processing construction 2." For example, when preparing a land cover classification chart from satellite data by using supervised maximum likelihood classification, it is necessary to prepare training data in advance as control file. The description of the control file in SSE-Web simply follows the form specified in advance, and does not require any complicated processing operations on the part of the user.

## 5. User interface design of SSE-Web

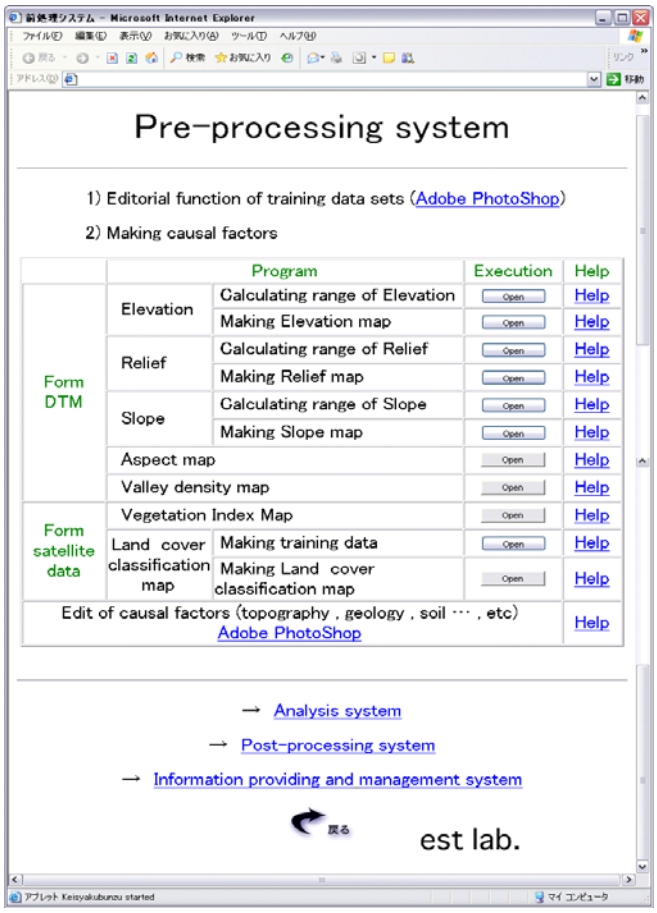



**Fig.6** Menu of pre-processing system.

### 5.1 Main menu of SSE-Web

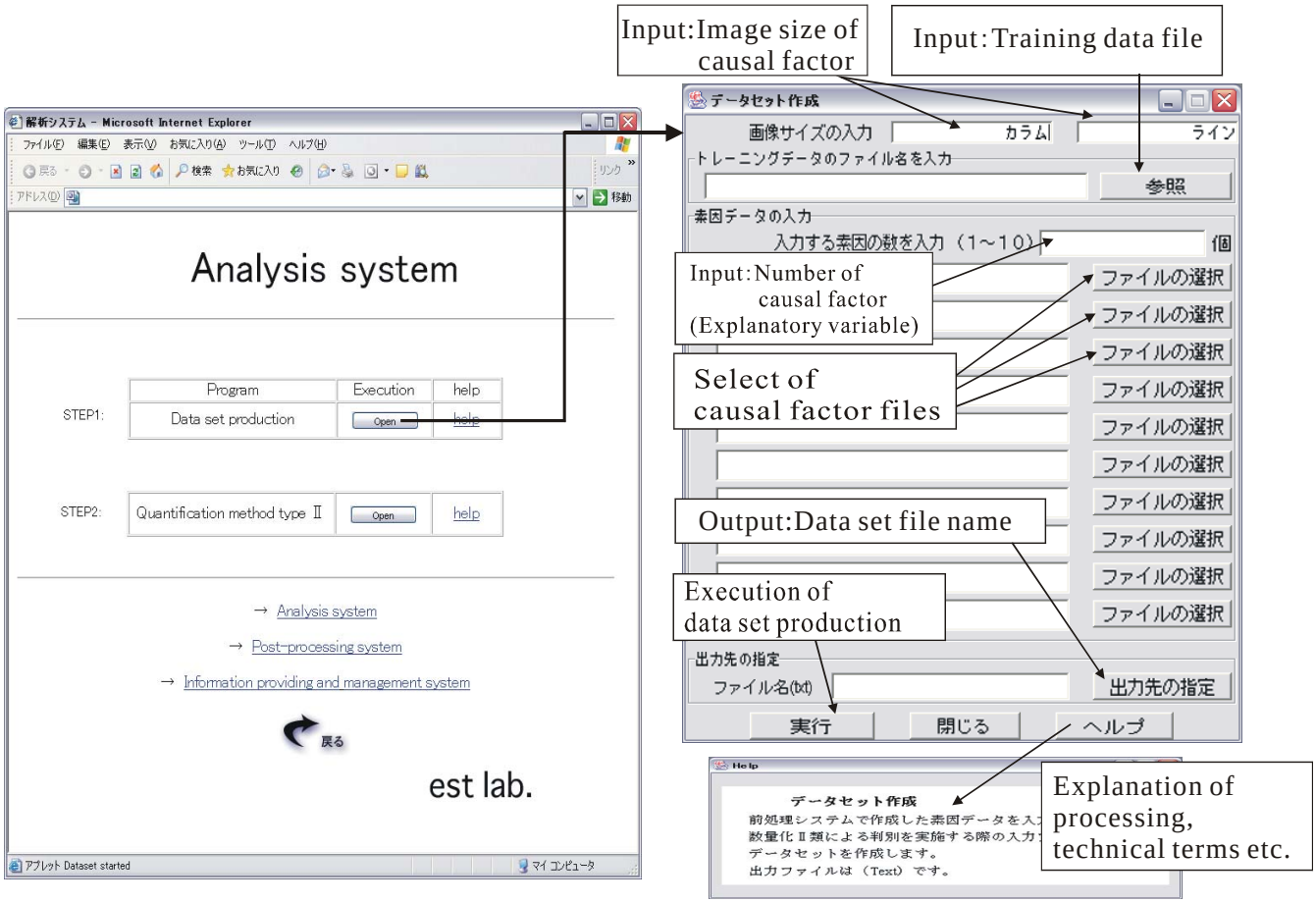
When an authorized user of the system (approved with password) operates the Web browser, the main menu of SSE-Web indicated in **Fig. 5** is displayed. By operating in the order of the numbers (pre-processing, analysis, post-processing, information supply & management) on the menu, the user can perform a series of processing regarding slope stability evaluation. In the following sections, explanation will be given on various points of special idea, etc. in design, together with description of the picture information.

### 5.2 Pre-processing system

The pre-processing system prepares causal factors (explanatory variates) and training data (purpose variates) as input information necessary for the preparation of slope stability evaluation map. **Fig.6** indicates the menu of the pre-processing system. The causal factors forming the subject of preparation are selected to proceed with the processing.

**a) Preparation of causal factors**

The causal factors can be classified into 3 different types i.e. (i) causal factors prepared from DTM (Digital Terrain Model), (ii) causal factors prepared from satellite data,




**(a)**Menu of analysis system

**(b)**Example:control panel design of data set making function

**Fig.7** Menu of analysis system and functions for data set production.

and (iii) causal factors prepared based on field survey, etc.

(i) Causal factors prepared from DTM

"Height division, amount of ups and downs, inclination classification, slope aspect, valley density" are prepared from DTM (Digital Terrain Model) through computer processing.

(ii) Causal factors prepared from satellite data

These are causal factors prepared through processing of satellite data. In SSE-Web, two different types of "vegetation index and land cover information" can be prepared. A plurality of vegetation indexes can be selected and/or prepared, as described earlier.

(iii) Causal factors prepared based on field survey, etc.

In addition to the above-mentioned causal factors, there are causal factors which are prepared through field survey, etc. of "topography classification, surface geology, soil, existing vegetation map," etc. Although some of such data are digitized and available on the market, it is necessary to digitize the drawings and edit them, in the case of paper medium. This processing can be made by selecting "edit/prepare other thematic map" on **Fig.6**, and linking to the general image processing software.

**b) Preparation of training data sets**

In parallel with the preparation of causal factors (explanatory variates), it is necessary to prepare training data (purpose variates) serving as discrimination standards in the preparation of slope stability evaluation map in advance. To be concrete, you select "edit/prepare discrimination standards data" and move to the general image processing software, to prepare and edit training data. The training data serving as discrimination standard (purpose variates) are classified into the following 2 types:

(i) Current type training data (discrimination standards)

Current type training data refers to discrimination standards data turned into images by putting the points where failure took place as "1" and other data as "0". This is a training data utilized for evaluations made in search of points having land properties similar to those of past landslide occurrences.

(ii) Model type training data (discrimination standards)

Model type training data refers to discrimination standards data turned into images by putting the points which are estimated as susceptible to a risk of failure even if no failure took place in the past as "1" and other data as "0". This is a training data utilized for analyzing differences in slope stability evaluation map (sensitivity analysis), in

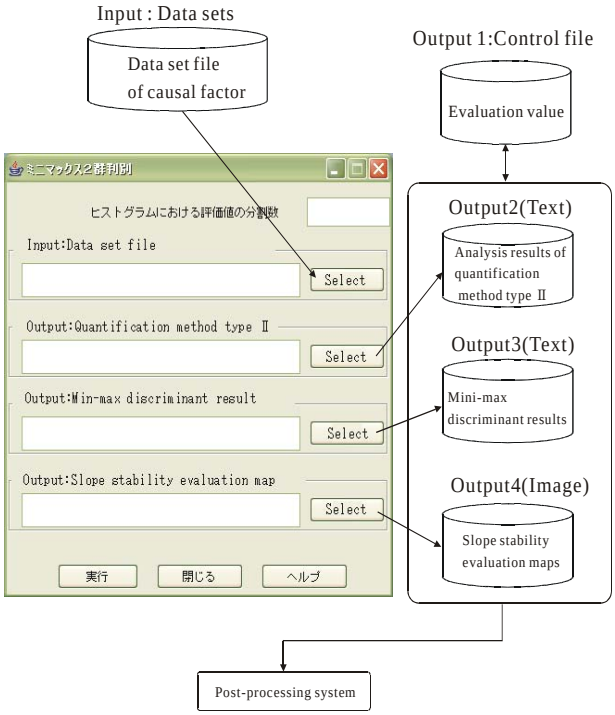



**Fig.8** Control panel for making slope stability evaluation map.

supplementation to the current type training data.

After completing the preparation of respective causal factors with the above-described pre-processing system, you returned to the main menu and then move to "analysis system".

### 5.3 Analysis system

**Fig.7 (a)** indicates the menu of analysis system. The menu items correspond to the flow of processing from top to bottom, and make the following 2 types of processing:

・Preparation of data set (Step 1)

・Preparation of slope stability evaluation map (Step 2)

**a) Preparation of data sets (Step 1)**

This processing turns the "causal factors and training data" prepared with the pre-processing system, and converts the format so that the data may be arranged in a way to be utilized for analysis based on quantification method type II.

If you select the "OPEN" button corresponding to "Prepare data set" on the menu of **Fig.7 (a)**, the control panel indicated in **Fig.7 (b)** is displayed. This control panel is composed of only the following 4 components:

・Parameter input

・Selection of input file

・Specification of output file name

・Execution

On SSE-Web, processing can be executed with those 4 specifying operations only, securing simplicity and uniformity of operation. Furthermore, it enables to execute and complete one round of processing, through a single control panel, by avoiding

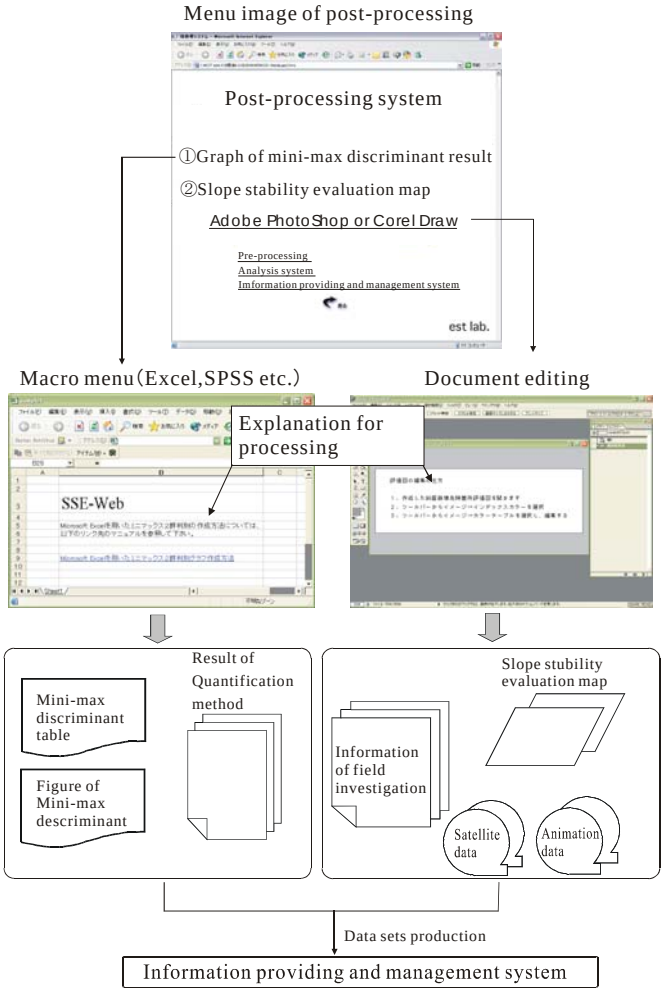



**Fig.9** Menu of post-processing system.

stratification of the control panel.

If you select the "Execute" button in **Fig.7 (b)**, after specifying input information, the results of processing submitted to data setting with the specified output file name are output.

**b) Preparation of slope stability evaluation map(Step 2)**

In this processing, slope stability evaluation is implemented with the data set file prepared in Step 1 as input. If you select the "Open" button corresponding to the "Slope stability evaluation map" on the menu in **Fig.7 (a)**, the control panel indicated in **Fig.8** is displayed.

By simply selecting the "Execute" button, after selecting and specifying the data set file name and output file name, the following 3 kinds of file are output:

・Results of analysis of quantification method type II

・Results of (analysis by) Mini-max discriminant method

・Slope stability evaluation map

Those files are processed and edited with the post-processing system to be described in the next paragraph, and attached to a written report, etc. If a data set of slope stability evaluation map is prepared in advance, the analysis starts from Step 2, facilitating trial studies.

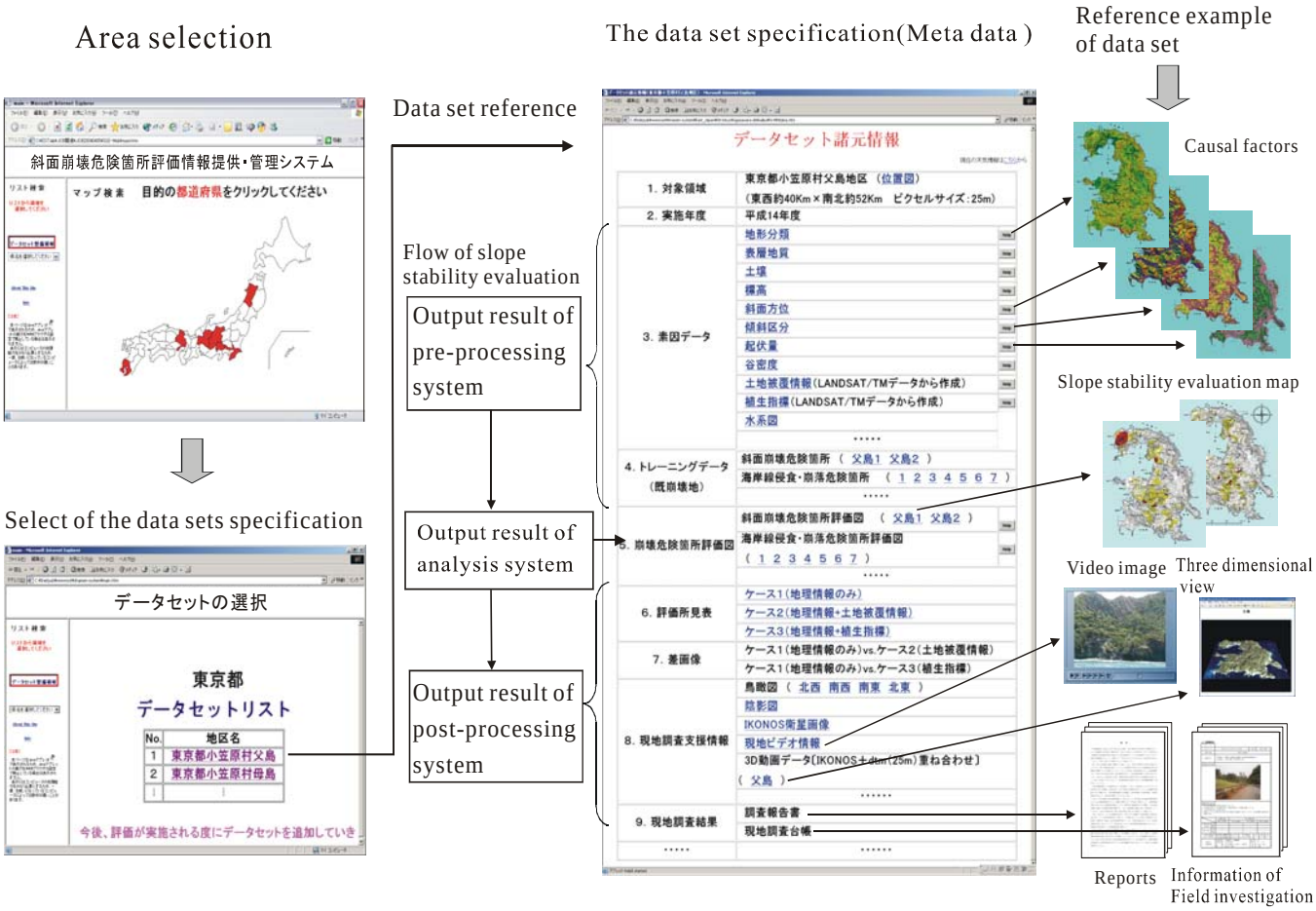



**Fig.10** Information supplying system.

**Fig.8** indicates the control file inside the system. This shows the results of calculation of evaluation value to be furnished to each picture element after execution of the analysis based on quantification method type II, and serves as input data for discriminatory processing by Mini-max discriminant method.

### 5.4 Post-processing system

The post-processing system performs editing for pasting the results of processing and analysis to the report. If you select "3. Post-processing system" on the main menu (**Fig.5**), the "Post-processing menu" indicated in **Fig.9** is displayed. It takes charge of the following 3 different kinds of processing:

- Editing of slope stability evaluation map
- Preparation of graph by Mini-max discriminant method
- Preparation of table of results of analysis for quantification method type II

The editing of slope stability evaluation map is made with a widely employed general image processing & analyzing software (Photoshop, Coreldraw, etc.). The results of processing of graph by Mini-max discriminant method and quantification method type II can be treated with tabular calculation software (Excel, SPSS, etc.). Those softwares can be linked by induction from the menu picture of the post-processing system, and a commentary is displayed during an operation. This does not require any special learning, and is a good news for engineers engaged in a wide variety of operations in the execution of their duties.

### 5.5 Information supply & management system

Various types of information such as causal factors, slope stability evaluation map, etc. are prepared, through the processings described so far, and they are integrally managed in units of geographical areas and jobs as data set.

The user side (client side) can utilize only the reference function of the information, while the system controller side (server side) takes charge of the management of data set. The data set prepared on the user side can be registered by being transmitted to the system controller. At that time, possibility or not of registration of the data set is judged on the user side. In the same way as the pre-processing, analyzing and post-processing systems, only authorized users for access can utilize the information supply & management system.

On the information supply & management system of SSE-Web, all information output from the pre-processing and the analyzing system can be referred to by linking at data set specification (meta-data). **Fig.10** indicates an example of data set specification (meta-data), including the relation of correspondence between the "information supply & management system" and the "pre-processing, analyzing and post-processing systems". The flow of search is composed

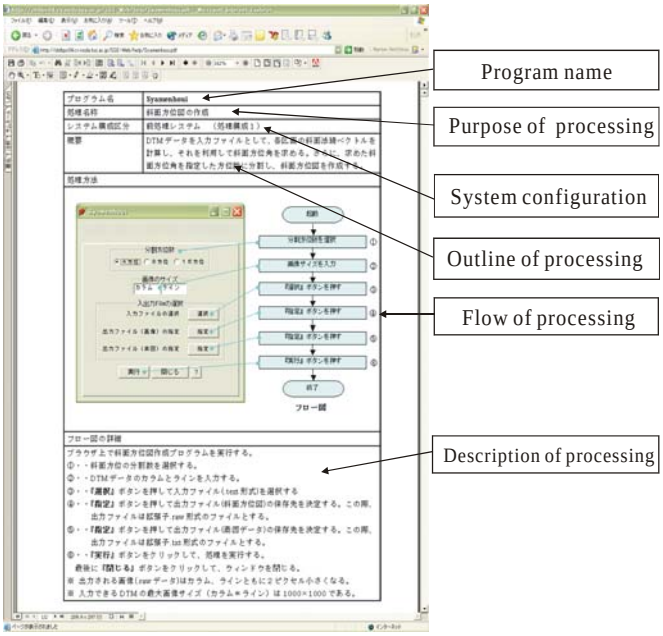



**Fig.11** An example of manual.

of the following steps:

・Selection of search area

・Specification of data set specification (meta-data)

・Reference to various kinds of information

Possibility of not only integrally controlling & sharing the information produced in units of job but also utilizing that information for further expansion of business operations also characterizes SSE-Web as induced link system operating under the Internet environments.

### 5.6 Operation manual

SSE-Web, on which the transition of pictures corresponds to the flow of processing, enables the utilizer to perform the processing easily without referring in detail to the operation manual. However, it is desired that reference be made possible also to basic technical information such as meaning of causal factor, contents of slope stability evaluation model (quantification theory, Mini-max discriminant method), etc. at the same time with the flow of processing.

For that reason, the operation manual of SSE-Web contains an explanatory description given by putting the control panel in correspondence to the flow of processing, as shown in **Fig.11**.

## 6. Processing efficiency

For operating a processing & analyzing system of technical line working under the Internet environments, it is necessary to clarify the processing efficiency of the system. In the present study, we decided to measure the "program execution time" base a conventional model operating under the UNIX environments (hereinafter referred to as SSE-UNIX), and compare it with that

**Table 2** Comparison of CPU times.

(Unit: Second)

| | Processing | | | SSE-Web (Java language) | SSE-UNIX (C language) |
|---|---|---|---|---|---|
| Pre-processing system | Image revision | | Geometric distortion correction 1 (Calculation of coefficient of affine transformation ) | 5 | 3 |
| | | | Geometric distortion correction 2 (Resampling) | 10 | 7 |
| | Production of causal factors | For DTM | Elevation | 4 | 2 |
| | | | Slope | 4 | 3 |
| | | | Relief | 4 | 2 |
| | | | Aspect | 8 | 3 |
| | | | Valley density | 5 | 3 |
| | | For Satellite data | Vegetation index | 5 | 2 |
| | | | Making land cover classification map (Supervised maximum likelihood classification) | 8 | 5 |
| Analysis system | Slope stability evaluation (Quantification method type Ⅱ, Mini-max discriminant method) | | | 4 | 3 |

Note) Image size :600 × 300(pixels).

of SSE-Web. The image processing & analyzing program provided on SSE-UNIX is fully coded in C language. **Table 2** indicates the results of comparison of program execution time. The size of the object image is 600x300 pixels.

"Program execution time" is the time counted from the moment you select the "Execute" button, after completing the input of various kinds of parameters and the selection of input/output files, up to completion of all the processing steps. It is "CPU TIME" as it is generally called, and is used as an indicator for evaluating the processing performance by modules.

As it is apparent from **Table 2**, the processing time of SSE-Web is different only in units of second compared with SSE-UNIX and may therefore be considered as presenting no problem in practical use.

## 7. Conclusions

In this research and development, we constructed a slope stability evaluation system the processing function of which is shared to operate under the Internet environments, SSE-Web as it is generally called, for the purpose of supporting wide area stability evaluation of slopes. The contents of the research and development may be summarized into the following items:

**a) Defining requirements of system development**

After clarifying the needs and significance of development of slope stability evaluation system operating under the Internet environments (Chapter 2), we studied basic requirements to be provided on SSE-Web, and reflected the

results in the system design.

**b) Study of system construction**

After setting the system construction categories (**Fig.1**: pre-processing, analysis, post-processing, supply & management of information), we proceeded to general design and detailed design of SSE-Web, and arranged design guidelines for system construction, including sharing of element functions required under the Internet environments.

**c) Building a guided linkage system**

We conducted slope stability evaluation, through "pre-processing system, analysis system, and post-processing system", and realized a guided linkage system capable of turning all information deal with by the system into data set in units of geographical areas and integrally controlling that information. This system can be positioned as a case of development not to be seen in any existing study, as a slope stability evaluation system operating under the Internet environments.

The following points may be mentioned, as prospect for the future:

**a) Expansion of analysis functions**

While an evaluation model based on quantification theory was loaded on the analysis system of SSE-Web, we also proposed other evaluation models based on probability model (Baysian model, fuzzy set model, certainty model, for example) in addition to it, on which studies from the viewpoint of accuracy theory are also being conducted[4]. Adding those models to SSE-Web to make them available for selective utilization can be expected to contribute to the progress of studies in the future, such as utilization of solution to various types of evaluation model, improvement of evaluation accuracy, etc.

**b) Continued accumulation and supply & management of data set**

SSE-Web is realized as a system open to growth, capable of accumulating, supplying and managing the processing & analysis information consecutively as data set in units of geographical areas. By utilizing the advantage of this system operating under the Internet environments, we are continuously promoting accumulation of data set of various kinds of operations implemented by these authors.

During the past several years, the contents of research regarding system development greatly shifted to development intended for operation under the Internet environments.

A lot of people pay attention to operation of ASP (Application Service Provider) also in the field of construction, but a fact remains that doubt is cast on the operating effect of processing & analysis system of technological line under the Internet environments.

It is therefore important to promote development and operation of the system, by constantly conducting analysis of application work bas on the contents of technology in the specialized field to grasp the effects and limitations of system operation under the Internet environments.

The contents of this research and development are positioned in the research field regarding system development aiming at integrated utilization & analysis of spatial information[9], and we shall be happy if they can contribute in some way or another to various types of research and development in the future aiming at developing & operating various kinds of highly specialized processing & analysis systems of technological line in the field of construction under the Internet environments.

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