PLANNING OF SECOND N-S FREEWAY (KUANHSI-HSINCHU SECTION) IN TAIWAN

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ABSTRACT

In order to relieve the traffic congestion on the existing Chung Shan Freeway it was decided by the government in 1985 that a second freeway be built in the northern region of Taiwan, ROC, with a total length of 86.5 km. Moh and Associates, Inc. was responsible for the planning and design of the southernmost section with section length of 20.4 km, running from Kuanhsi to Hsinchu. The route corridor of the section crosses undulating terrain with complex geological conditions. The topographical and geological conditions are two of the major factors influencing the planning work of the new freeway. This paper describes the procedures and considerations that have gone into the planning and design of this section with respect to the major features, such as route selection, slope stabilization and its protection, structure types, and landscaping-related highway engineering. In addition, modern design concepts and new construction methods were introduced with care, including the use of a computer-aided design and drafting (CADD) program system.

INTRODUCTION

The Kuanhsi to Hsinchu section of the new second freeway in the northern region of Taiwan, ROC, extends from its connection with the preceding section on the northern side of the Fengshan River, at proposed chainage of 66K+100, to the intersection with the existing freeway in Hsinchu at proposed chainage of 86K+500. Along the project route two interchanges, at Chiung-Lin and Hsinchu, are proposed to connect with local roads and the existing freeway.

Geological conditions along the Kuanhsi-Hsinchu section Northern Second Freeway project are quite complex, including hill areas, terraces, and recent alluvial plains, and encompassing extreme differences in elevation. Most of the geological formations are composed of interlayered sandstone, shale, mudstone and gravel. The engineering properties of these formations are for the most part weak, poorly cemented, with high permeability and low slake durability. These formations are easily weathered and eroded.

Based on the results of the geological field reconnaissance, aerial photo interpretation and geophysical exploration, numerous potential disaster areas were identified along the proposed route. These include fault zones, synclinal axis, recent landslide areas, colluvial deposits, headward erosions and bank erosions. All of these areas require propoer treatment in order to maintain highway safety and to minimize environmental impact. Extreme variations in topography make deep cuttings and high embankments unavoidable. Suitable landscaping to restore the original environment is, therefore, necessary.

The project route also runs across numerous valleys, rivers, steams and irrigation channels. Due to the extremely undulating terrain, long bridges with high piers and diversions of streams and creeks are needed. The negative impact on the surrounding environment of these numerous structures was carefully investigated.

Through careful study of the considerations stated above, a balance of engineering safety, economy and environmental impact has been achieved. Project construction began in mid-1988 and is anticipated to be completed in approximately four years.

DEVELOPMENT OF COMPUTER-AIDED DESIGN AND DRAFTING (CADD) SYSTEM

In order to increase the efficiency, accuracy and quality of the design and drafting work, a special team was organized at the early planning stage to develop the CADD system. The task force was composed of engineers experienced in highway, structure, construction and computers. By way of a series of workshops, the special team first set up the specifications of the system. Based on the specifications, the software was developed to fit the requirements of the project, whilst also maintaining flexibility for future extensions or revisions to suit other projects. Using the specifications, hardware systems on the market, including work station networks, hard disks, and plotters, were evaluated and selected. A series of professional software programs was developed and put into production. This series can be divided into two major parts, namely highway design and structural design.

For hihgway design, the software package is able to carry out all calculation of geometric design in alignment and profile, quantity of cut and fill, etc., and can produce full set of drawings for construction and land acquisition purposes. The calculation and drawings were made base on the terrain data stored in computer database, the highway data input and slope design criteria. The terrain data in the project was obtained by manual measurement on the contour map, but the system can also accept digitized terrain data. The drawings produced by the CADD system include:

(1) contour map
(2) highway alignment and profile
(3) road cross section, including cut and fill slope
(4) plan of cut and fill
(5) right of way
(6) interchange
(7) mass diagram
(8) perspective of highway in motion.

For structural design, the software package is able to execute structural analysis and section design for box culverts and simply-supported I-girder bridge systems. The drafting capability includes the production of drawings for the following structural components:

(1) plan and cross section of culvert, detail of wing wall and head wall
(2) plan and detail of bridge deck

(3) detail of precast I-girder
(4) plan of girder framing
(5) detail of pier bent and foundation.

Attached to the software system is a drafting database which collects all the symbols and components to be used for the drawing. The database was generated gradually during the planning and design stage and will be further expanded in the future by adding new items and groupings. With the CADD system and its database, over 40 percent of the drawings in this project were prepared by computer.

ALIGNMENT-MAIN ROUTE AND INTERCHANGES

Main Route

The proposed route was planned following careful consideration of the natural and cultural conditions of the region, such as climate, hydrology, geology, topography, mountain ridges, land use, major utilities, farmland distribution, and location of communities. Its location was also selected to fulfill the following guidelines and criteria:

(a) to correspond as closely as possible with the natural terrain,
(b) to maintain the original functions of natural and artificial water systems and of existing roads,
(c) to avoid passing through areas of potential geological disaster,
(d) to achieve a target balance of earthwork,
(e) to minimize housing demolitions,
(f) to coordinate with local demands and other major projects
(g) to allay the longitudinal profile in order to promote service level, and
(h) to combine the horizontal and vertical alignment as best as possible to increase utility and safety, encourage uniform speed and improve appearance without additional cost.

After thorough evaulation and comparison of alternatives, the final route was chosen as shown in Fig. 1. The applicable items for evaluation and comparison of the alternatives were as follows:

(a) alignment including the status of overall length, allocation of horizontal and vertical alignment and their combination, geological condition and landscaping,
(b) engineering cost for calling tender,
(c) construction duration and conditions,
(d) maintenance cost and conditions,
(e) serviceability on the development of adjacent areas in future and the efficiency of interchanges,
(f) house demolition, including quantity and its resistance,
(g) impact on local traffic and residential living conditions during construction stage,
(h) operating conditions related to safety, comfort, weather and terrain,
(i) use of lands and utilities,
(j) interferences related to other projects, and
(k) impact on the environment.

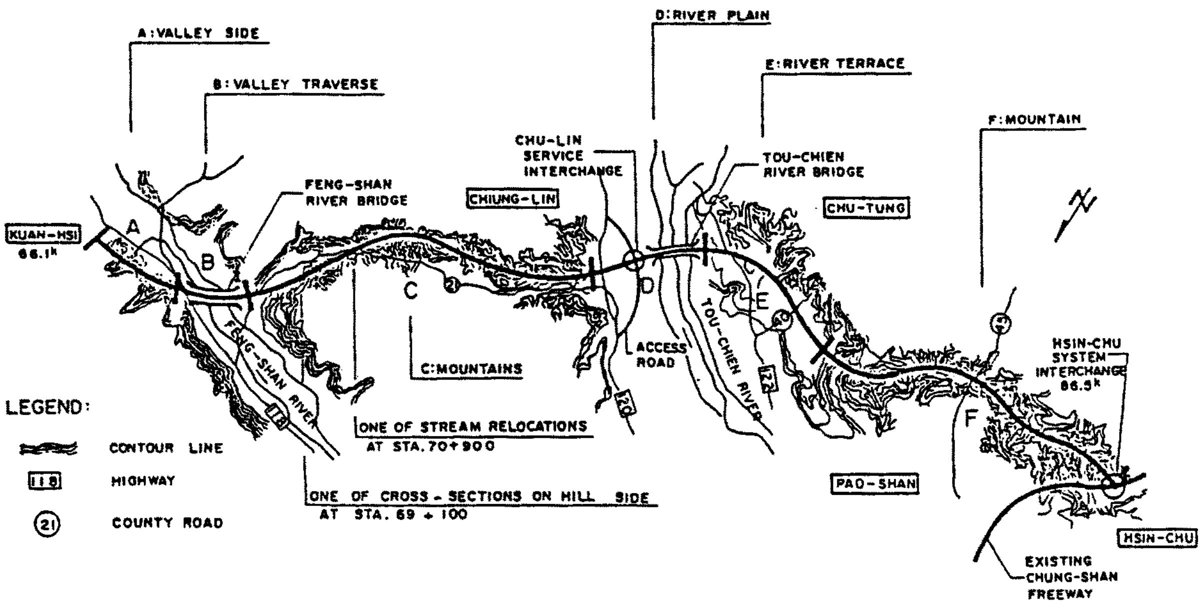

Figure 1. Layout of proposed Kuanhsi Hsinchu section Taiwan northern region second freeway

Interchanges

There are two interchanges in this section, one required in the Chiunglin-Chutung area and another one at its intersection with the existing Chung Shan Freeway. Based on the result of the analysis performed on the regional urban development, traffic characteristics and transportation demand, it was revealed that a service interchange is needed in the Chutung and Chiunglin areas. Two possible sites for this interchange were considered, one located at Chutung and the other located in Chiunglin. A thorough evaluation and comparison of these two sites has been carried out, and the results indicated that the Chiunglin area site will be more appropriate to the function of this interchange. The elements considered in the evaluation and comparison were:

(a) service area and service distance to the adjacent major towns or cities,
(b) degree of interference on adjacent area activities and city district traffic,
(C) regional development potential,
(d) present traffic operation patterns, and
(e) topography of the site.

The planning of this interchange was based upon the requirements for the conflict traffic volume, signal control, land use, and construction cost. After thorough study, a single leaf diamond was selected as the most desirable type, as shown in Fig.2. A system interchange should be provided at the junction of the existing Chung Shan Freeway and the Northern Second Freeway in order to furnish entrances and passageway for the traffic between the two freeways. Furthermore, the Northern Second Freeway will be extended southward to the central and southern regions of Taiwan in order to perform a whole Second Freeway Network in Taiwan. In planning this interchange, the problem of how to meet the requirements of and how to connect with the Central Second Freeway was also carefully considered. Unfortunately, whether the second freeway corridor in the central region will adopt a coastal line or inland line as recommended in its feasibility study would not be determined in the near future. Therefore, a flexible design of the double trumpet type constructed in two stages, has been developed, as shown in Fig. 3, in order to accommodate the present situation and future conditions, whether the Central Second Freeway has inland line or coastal line. In the first stage, a single trumpet type interchange will be constructed in order to meet the present requirements. After the Central Second Freeway corridor is determined, the second stage work will proceed. If the coastal line, which will intersect the Chung Shan Freeway at the said interchange as shown in Fig. 3, is selected, another single trumpet will be constructed and thus create a complete system interchange of the double trumpet type. If the inland line, which will connect with the Northern Second Freeway at another location, is seclected, the system interchange will remain a single trumpet without second stage construction.

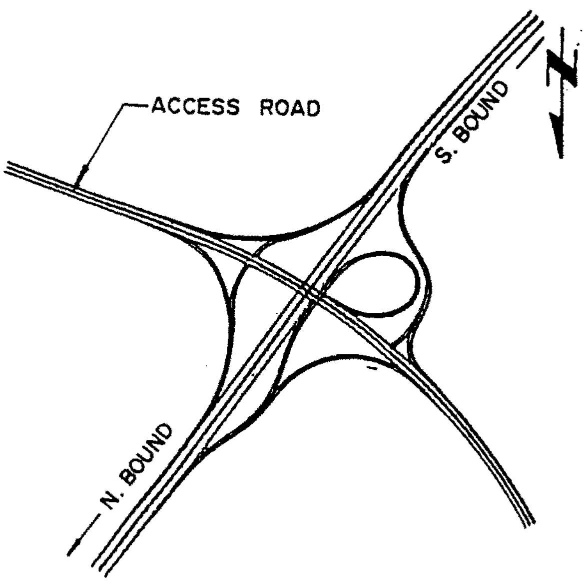

Figure 2. Chu-Lin service interchange

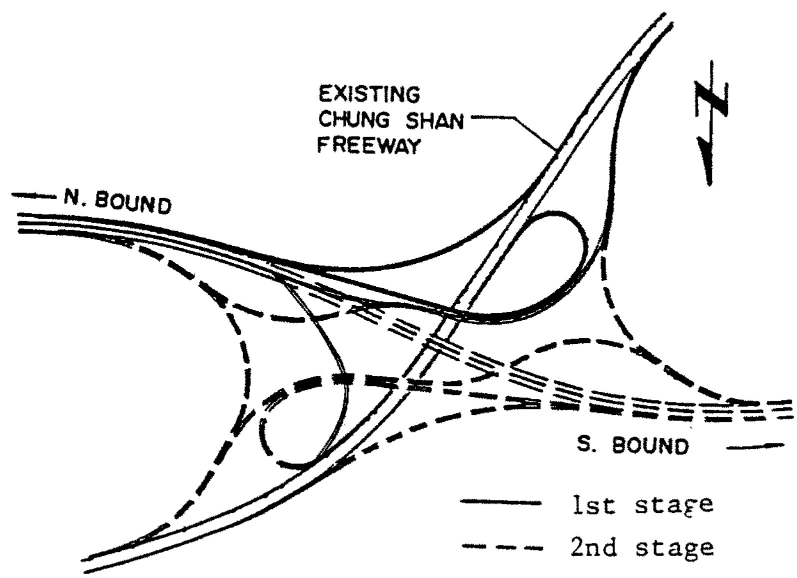

Figure 3. Hsinchu system interchange

STRUCTURES

<u>Factors Considered in Planning</u>

The proposed Northern Second Freeway section passes through a hilly area with fluctuating terrain. Major rivers, small creeks and local roads are scattered along the route, thus requiring a large quantity of bridges and culverts. In the final design, there are a total of 39 bridges of 95,000 sq.m. deck area, 68 culverts of 4,900 m length, and 3 elevated flumes of 260 m length along the 20.4 km freeway section. In the planning and design of these structures, the following

considerations were accounted for in scheme determination:
(1) Most bridges have high piers due to the fluctuating terrain. Earthquake-resistance capability turns out to be a governing factor for bridge design.
(2) Unstable river bed and high pier limit the bridge type to unshored construction method.
(3) Bridge foundations without concern of scoring may use direct footing due to favorable soil conditions with the bearing layer located within a few meters below the ground. Foundation of river bridges subject to scoring will use deep foundations such as sinking caissons or bored piles.
(4) Long culverts with thick backfill on soft topsoil needs special details to accommodate long-term settlement, especially in the case of drain culverts.
(5) Aesthetic treatment shall be considered in structural design to enforce harmony with the quite beautiful natural environment of the area.

The 39 bridges in the proposed freeway section can be categorized according to their function as follows:
(1) 3 river bridges,
(2) 13 overpass bridges,
(3) 9 underpass bridges, and
(4) 14 channel bridges

Structure Type

Most bridges are of conventional type, either simply-supported precast I-girder with cast-in-place deck slab or continuous box girder constructed with shoring. The former type is used in underpass and channel bridges. The latter type is used in overpass bridges. Architectural planning and span arrangement are the two key factors in the design of overpass bridges which shall match with the configuration and landscape of the freeway out section. Span of the two types of bridges is of medium range from 25m to 40m for precast girder and up to 50m for continuous span. Design and drafting of conventional bridges were performed using the CADD system, which is a software package prepared by the computer team of this project.

Besides the conventional bridges, there are several bridges which need special study in terms of both aesthetic and economic aspects. Among these are two river bridges crossing the Feng-Shan River and the Tou-Chien River. Length of the two bridges are 633.6m and 793m, respectively. Both bridges have 3 lanes and 16.4m deck width in each direction. At the planning stage, five different bridge schemes were selected for study and evaluation as follows:
(1) 40m span simply-supported precast I-girder.
(2) 50m span simply-supported steel plate girder.
(3) 60m span continuous box girder by cantilever construction method.
(4) 60m span continuous composite steel girder.
(5) 80m span continuous composite steel girder.

criteria used in the evaluation include landscaping compatibility, earthquake-resistance capability, constructibility and foundation cost. Nominal requirements for river drainage stipulate only medium span bridges in general. The 80m span composite steel girder and 40m span precast I-girder were recommended in the conclusion of study for the two bridges. Both bridges will use sinking caissons for their foundation. However, the use of value engineering at the early design stage has led to an alternative scheme of single-cell continuous box girder constructed by an incremental launching method. The alternative scheme was carefully evaluated and finally adopted because of the economic span which falls into a favorable range for both of the bridges. Besides the economic considerations, the original profile and alignment can be maintained by using the launching method. In the proposed construction plan, Feng-Shan Bridge will have a full-length bridge deck pushed from the high end, and Tou-Chien Bridge will have two continuous segments pushed from both ends. Although the bridge deck is heavier than in the original schemes, continuous decks over several piers have provided adequate redundancy in earthquake resistance. Under the same study, drilled piles with grouting along the shaft and at pile tip were adopted place the original caisson foundation. This major change in scheme was made in the concern of evergrowing problem of labor shortage and limitation in labor safety imposed by new government labor laws. Introduction of the alternative schemes both in bridge structure and foundation has helped cut down the construction cost for two bridges by 30 percent, and more important has also significantly reduced the risk in conventional labor-intensive construction. Beyond the technical considerations, adoption of advanced construction concepts and methods also conforms to the government policy of technology transfer in the construction industry.

The incremental launching method of bridge construction, though developed and applied for many years in other parts of the world, is still a new application in the local market. Nevertheless, the method, characterized by its "pushing process" is very simple in concept. The bridge deck is cast segment by segment in factory-like casting yard located at the back of the abutment at the pushing end. When a segment is cast and cured against the previous segment, the whole completed deck is pushed forward to leave space for casting yard for the next segment. This process is repeated until the full length of continuous deck is cast and pushed into place. During the pushing process, a nose girder or truss, usually built of steel, is erected in front of the first segment to help reduce the moment and shear in the pioneer section when the deck is in cantilever position. Special sliding bearings will be placed at abutments and piers to ensure low friction force during pushing, which eventually will be replaced by permanent bearings when the pushing process is completed. High quality and cost-efficient production can be achieved due to a factory-like casting process. A seven-day cycle for one segment of half-span length (achieved after a short period of practice) has been demonstrated in the past. Under its simple concept, a construction system package covering equipment, monitor and control procedure with strict requirements as to tolerance will be set up to ensure the successful performance of the method.

GEOTECHNICAL ENGINEERING

Topography

The areas cut through by the alignment are mostly hilly terrain, and the rest are terraces and alluvial plains. The hills are generally less than 250m in elevation. Surface elevation of this region is found to vary substantially, and is in general descending from south to north.

Terraces can be subdivided into laterite terraces and non-laterite terraces which are sporadically found near the northern boundary of the hilly area as well as the banks of the Feng-Shan and Tou-Cheng Rivers. These terraces are generally flat, with elevations somewhere between those of the hills and alluvial plains. Generally speaking, the laterite terraces are higher in elevation than the non-laterite terraces.

The alluvial plains are located in the watersheds of Feng-Shan and Tou-Cheng Rivers. The Feng-Shan River runs through Kuanghsi and Chunglin areas, while the Tou-Cheng River runs through the Chunglin and Hsinchu areas. The alluvial plains are generally low and flat.

Geological Characteristics

Based upon the results of aerial photo interpretation and surface geological survey, the geological condition along the alignment is presented in Fig. 4. Most of the ground surface is covered with vegetation. According to the geological era, the exposed ground can be divided into the following formations: the Pliocene Cholan Formation, Plio-Pleistocene Tokoushan Formation, Late Pleistocene laterite terrace deposit, non-laterite terrace, and alluvium. The composition and characteristics of each formation are summarized in Table 1.

Potential Geological Hazards and Related Engineering Problems

(1) Faults

Hsin-Chen Fault is the most important tectonic line in this area. It stretches for more than 18 km in length and the fractured zone is more than 50 m in width. The rock stratum in this area is geologically young; it is in general very soft and susceptible to erosion. The presence of the fault further complicates the structure of the rock stratum, fracturing and weakening the rock and causing large or small scale landslides in various locations.

Besides the Hsin-Chen Fault, there are also the Sa-Ken-Tze, Chunglin , and Chi-Ko-Liao Faults scattered around this area. The fractured zone of these faults are, in general, limited to about 10 m width. The bedding planes of the rock stratum situated near the faults are usually disrupted.

The areas disturbed by the presence of faults generally contain large amounts of groundwater and should be avoided when possible. When the route has to cut through faults, the locations of faults have been ascertained via the use of geophysical prospecting. Important structures and massive excavations are located away from the faults.

Moreover, due to the disrupting effect of faults,

Fig. 4 Geological Map of Kuanhsi-Hsinchu Section, Taiwan Northern Second Freeway

the dip and strike of the nearby rock stratum may vary dramatically over a short distance. Cutting and filling in this area are likely to induce landslide along the dip slopes. The stability of slope will also be reduced as a result of the accumulated groundwater. Geological and groundwater conditions have been carefully studied before landslide preventive measures such as ground anchor, drainage and protective berm were considered for each specific case.

(2) Folds (anticline and syncline)

There are two major folds (anticline and syncline) found along the route, they are:
(a) Tung-Keng anticline and Chungkeng syncline, which run in a eastwest-westsouth direction. Lengths of the syncline and anticline are 1.6 km and 2.5 km, respectively. This fold is classified as a non-symmetric structure.
(b) Paoshan anticline and Kantzechi syncline, which is running in a northeast-southwest direction. The axes extend more than 10 km. The axis of anticline passes through a hilly area, which will encounter the alignment and result in cut slopes with broken rocks near the axis. The rock bedding planes near the axis have different dip angles and strikes, which is likely to affect the stability of slopes. For the dip slopes, protective measures such as ground anchors, drainage and protective berms were designed to avoid possible slides.

Since the axis of syncline is the lowest spot of folding rock strata, groundwater is likely to accumulate in this area. This characteristic of syncline can be identified in the field by groundwater seeping from the slope surface or a large number of ponds in a single area. The axis must be averted as much as possible, and for areas where the axis cannot be avoided, drainage has been provided according to the groundwater conditions to prevent scouring of the road foundation or slope. Slides and subsidence of the road foundation can be avoided.

(3) Existing Slides

Surface surveys show that existing slides are sporadic and situated in the hilly area. The slides can be attributed to factors such as steep terrain, unfavorable geological structure, loose ground material, inadequate surface vegetation, dip slope slide, removal of the toe material, and scouring.

Due to the varying nature of the ground conditions encountered in this general area, the existing slides were the result of different factors, such as poor geological conditions and scouring. The slides also assume different sliding modes and depths, and occur in different strata. Preventive or remedial measures such as flatter slope, drainage, anchorage and retaining structures have been adopted to avoid future additional slides.

(4) Dip Slope

The rock strata found near the alignment are usually disrupted by geological features such as faults and folds. The dip

Table 1 Topography, Geology and Engineering Property of Kuan-Hsi to Hsinchu Section

TOPOGRAPHY	AGE	FORMATION		CONSTITUENTS	ENGINEERING PROPERTIES
Hills	Pliocene	Cholan Formation		Sandstones, shales, Mudlstones and their Interlayers	Softrock, poorly cemented, Easily weathered, low Slake-Durability, easily eroded, Easily rippable, Sandstone with high permeability
	Plio-Pleistocene	Tokoushan Formation	Hsiang Shan Facies	Sandstones intercalated by thin layers of shales and Conglomerates	Softrock, poorly cemented high permeability, Easily weathered, Low slake-Durability Easily eroded, Easily rippable
			Houyuanshan Facies	Thick Conglomerates Intercalated by thin layers of shales and Sandstones	Easily eroded, poorly cemented, High permeability the Interstices filled by gravels sands and silts
Tableland	Pleistocene	Lateritic Terrace Deposits		Upper part: Several meters to ten meters of red soil Lower part: Several meters to fifty meters of gravel	Red soil of upper part: Highly compressed Gravels of lower part: Easily Eroded
	Holocene	Non-Lateritic Terrace Deposits		Upper part: Several meters to ten meters of soil Lower part: Several meters to fifty meters of gravel	Soil of upper part: Easily compressed Gravels of lower part: Easily Eroded
Alluvial Plains		Recent Alluvia		Clay, silt, sand and gravel	Alluvial Sediments, variable Constituents, Probably with some weak layers

angles of the bedding planes also vary by a wide margin. Geological survey on the outcrops near the alignment shows that the strikes and dip angles of rock strata may vary widely. Owing to the limitations of the planning requirements, the alignment inevitably cuts through several slopes with rock strata dipping toward the route. Dip slides along the shale or mudstone layer may occur on this kind of slope. The quality of rock, degree of weathering, as well as the distribution of cleavages and groundwater have been carefully studied in order to assess the stability of slopes. For slopes with inadequate stability, ground anchors, drainage and slope protection measures are adopted to stabilize the slope. In addition, the vegetation and appearance of the slope surface must not be destroyed.

(5) Talus and Soft Alluvium Deposit

The thickness of talus and soft alluvial material found along the route ranges from 5 m to 15 m. They are generally loose and highly compressible. Roads and structures built on top of this sort of material are expected to experience excessive amounts of settlement. Preventive measures such as replacing, preloading and recompaction of the soft materials have been adopted according to the in-situ conditions encountered.

(6) Headward Erosion and Debris Flow

A major part of the new freeway is in a hilly terrain, where heavy rainfall is likely to induce torrential flow along the valley. Since the rock strata in the area are generally loose and poorly cemented, they can easily be washed away by water flow, resulting in a well developed headward erosion. The valleys which will be cut through by the alignment all show patterns of headward erosion.

Debris flow is likely to be another common phenomena in view of the presence of widely found gravel-abundant hills. The gravelly hills are part of Houyanshan, which belongs to the Tokoushan Formation. It is well recognized that a gravel layer is susceptible to scouring effect of rainfall, and in many instances results in a debris flow.

To prevent the development of headward erosion and debris flow, the surface of the slope must be well protected to guard against erosion. A drainage system has also been planned to remove and avoid accumulation of surface water.

Monitoring System

Though the possible geological disasters related to this project have been investigated and preventive measures are undertaken, monitoring systems are still required for several large scale cut and cover slopes as well as the slopes with complicated hydrogeological conditions. Inclinometers and pizeometers will be installed to measure the ground movement and groundwater variations, respectively. Not only can the stability of slope during and after construction be ascertained, the monitoring results can serve as the basis for safety control and long-term slope maintenance.

Construction of the project will be greatly affected by the geological and hydrological conditions along the route.

The complex ground conditions as well as the occurrence of possible geological disasters has been described in detail. Fortunately, these aspects have been recognized since the beginning of this project. Ground characteristics and possible geological hazards were, therefore, carefully studied before commencing of the construction. It is perceived that as a result of modern construction technology, most of the potential problems have been overcome where encountered.

LANDSCAPING

The final route chosen was divided into six sections based upon characteristics of the terrain and ecology along the route and after an evaluation of the ecological environmental impact, an investigation into strategies for conservation was undertaken.

Since most of the portion of the proposed route is located in mountainous areas, the scenic view along the route is predominanly of rolling mountains and green plants. Such an attractive landscape should be appropriately preserved. Irreversible changes to the topography caused by cut and fill will be treated by planting of trees on slopes, thus endeavoring to recreate the natural landscape. Furthermore, planting at medians and on the surface of slope protection structures will help the slopes to blend with the surrounding scenery and improve the visual feeling of the roadside.

The topography of interchange site for example the Chu Lin service interchange located at Tou-Chien River Plain in Chiunglin, will be somewhat altered due to the construction. Therefore, in this area, special landscape planning will be undertaken as shown in Fig. 5. The essential points of the planning are:

(a) to distingush the character of the interchange and form a landmark, tall trees will be planted at proper locations;
(b) to produce visual leading effects and to attract the attention of motorists in order to enhance safety, planting will be undertaken along the sides of ramps and loops to provide visual landmarks;
(c) to create an attractive scenic view, landscaping was planned to encompass formal planting within the reserved land space of the interchange;
(d) to maintain the character of the plain, short plant species were chosen for planting along the sides of the road embankment;
(e) Tree-line planting is provided at the toe of the embankment, connecting with existing field boundary, windbreaks and successfully blending them with the scenery of the plain.

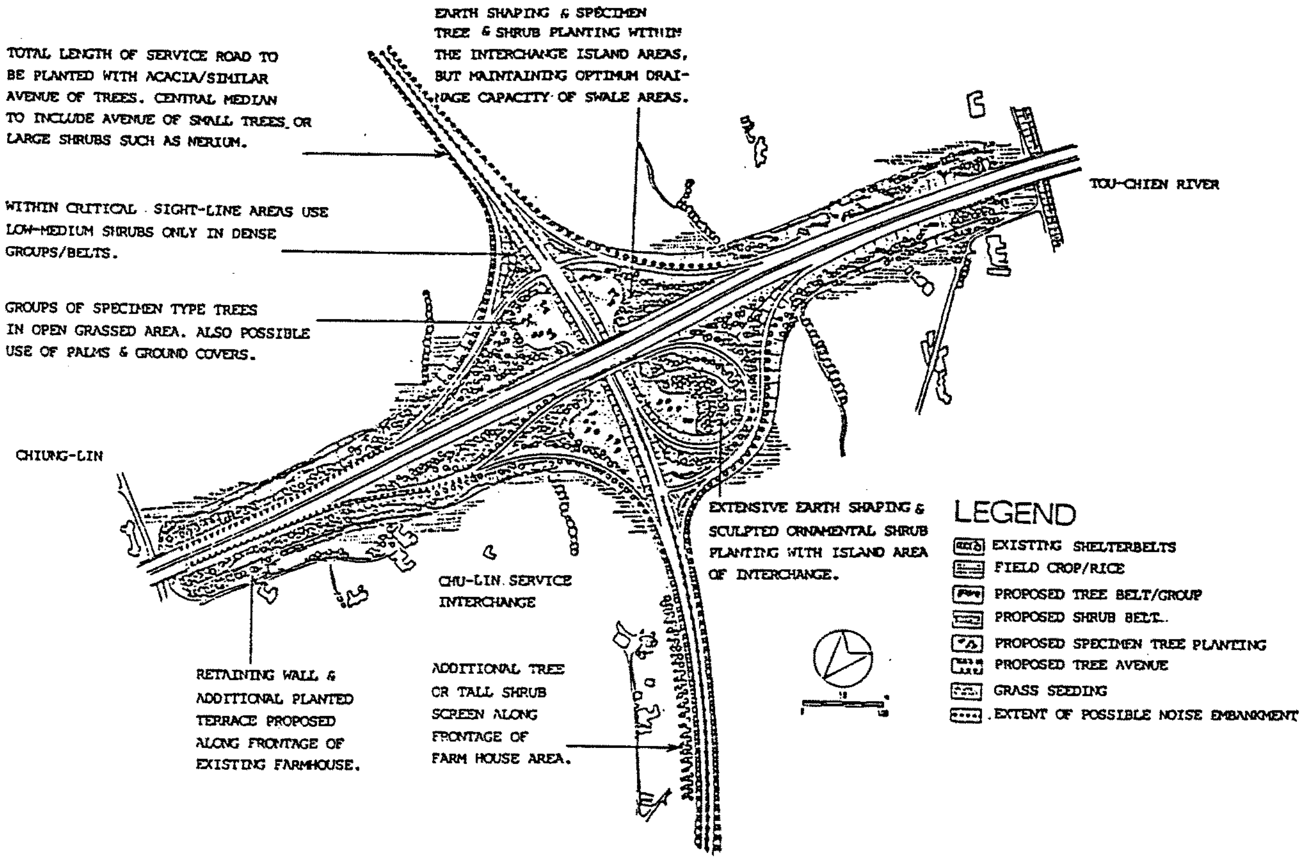

Figure 5. Landscaping plan for Chu Lin interchange

CONCLUSIONS

(1) The use of the CADD program, prepared before the commencement of planning and design of this project, ensured efficient and accurate design and drafting work.
(2) Supported by careful geotechnical analysis, the proposed section of the new second freeway was planned and designed with minimun environmental impact, least potential disaster, enforced safety proteciton, maximum landscaping beautification and economy.
(3) The incremental launching method was introduced into the project by the application of value engineering, thus reducing construction cost by 30 percent and construction time by one-third.
(4) The project establishes a model for a balanced emphasis on construction cost and environmental protection.

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