The Environment and Landscape in Motorway Design

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Since the world’s first motorway was completed in Germany in 1932, more than 80 other countries have built motorways, with a total length of more than 220,000 km.

European countries started quite early in the construction of motorways and made rapid progress in connecting motorways between cities and countries into a complete network. A well-developed motorway network and a smooth and efficient driving environment facilitate convenient access to these countries.

For motorway construction, European countries have paid special attention to environmental design. Full consideration is given not only to the layout, but also to whether the motorways can be integrated into the natural environment and landscape. In addition, road alignment and the visual and psychological impact on drivers and passengers are also considered in design. At present, these countries have made great achievements in terms of ecological protection and the use of information resources when constructing motorways. The environmental landscape is also very picturesque.

Motorway landscape design began in the early 1920s. Specialized landscape design was emphasized in the construction of Parkway in the USA, mainly focusing on how the motorway alignment would fit into the natural landscape as well as the protection and utilization of scenery along the route. In the 1930s, Germany first adopted an alignment model to check and correct space alignment and came up with an integrated design taking into consideration horizontal and vertical factors, thereby achieving optimum motorway design. Further progress was later made in motorway landscape design, such as using a customized model and plastic foamboard to design a route model and making perspective drawings using the optical projection principle.

Since the 1960s, many developed countries have begun to consider landscape design in motorway construction while attaching importance to the improvement of existing motorway landscapes, and these countries have also developed appropriate specifications and regulations. For example, in 1965 the United States issued the *Highway Beautification Act*, and *Development Guidelines of U.S. Interstate and Defense Highway Landscape and Guidelines for*
Highway Landscape; later, in 1970 they formulated Guidelines for Highway Landscape and Environmental Design and Practical Highway Aesthetics. All these specifications and regulations focus on visually attractive highways with basic functions which aim to be harmonious with the surroundings. They also published some basic principles, for example the diversity of the landscape along the route must be ensured in motorway design and the whole route should be scenic; the motorway must ‘adapt to the terrain’ without large-scale cutting and filling; harmony between the motorway and the surrounding landscape must be realized as far as possible; and the natural landscape must revert to its original state rapidly, or the natural appearance must be restored by appropriate planting and greening if damage to the natural landscape is inevitable in construction. Meanwhile, basic principles of landscape design have also been broadly adopted in the construction of motorways, trunk highways as well as scenic highways in other developed countries such as Germany, France, the UK and Japan. Regulations governing landscape design have been developed in relevant design specifications. In 1974, based on investigations of highway landscaping, the Ministry of Highway Engineering of the former Soviet Union developed and issued Instructions on Highway Architectural Art and Landscape Design. Landscape design has now become increasingly important in terms of highway design, and many countries have accordingly revised and issued relevant specifications and regulations.

European countries feature high forest coverage, good vegetation protection and appealing motorway landscaping. For the construction of the motorways, close attention has been paid to the protection of trees and restoration of vegetation on both sides of the motorway. For instance, the two directions of many motorways are separated so as to avoid damage to the hilltop, villages, woods, and rivers along the route (Figures 1 and 2). A service area near Stratford-upon-Avon in the UK is built on a hillside in order to preserve the

Figure 1  A motorway detours around a hill to protect the forest.
The two directions of the motorway are not at the same level in order to adapt to terrain features. Existing landscape, and the parking area, petrol station, stores and restaurants are all constructed according to the terrain features, surrounded by the original trees and grass on the hillside. On the motorway from London to Edinburgh, trees were planted at the entrance to a tunnel and at the top of the tunnel upon completion, in order to fit with the surrounding natural vegetation and woods and create an illusion that the motorway is running through woodland and grassland. In the light of local conditions, greening of the central reservation is achieved by accentuating natural and diversified features without pruning weeds, therefore the motorway can be integrated into the natural landscape on both sides.

France attaches great importance to culture and history. As for leisure facilities along motorways, they integrate natural and cultural elements and pay special attention to local customs and practices as well as local landscape features. For instance, trees and flowers are planted in service areas, including tranquil tree-lined trails with an enchanting view; durable and solid facilities for relaxation and recreation such as tables and chairs also fit into the surrounding environment; most of the car parks are in an area covered by green shade, thus creating space for both parking and rest. In addition, travellers have the opportunity to communicate with local residents to understand local life (Figure 3, Figure 4 and Figure 5). In Germany there is a large amount of forest, and many motorways pass through forest for a long distance. Numerous signs are provided on both sides of the motorway to remind drivers of passing wildlife such as red deer and foxes. Rest places for travellers are mostly built in forests along the route, thereby integrating the motorways with the natural surroundings (Figure 6). Motorway design in Germany is characterized by smooth, rational and natural design and rarely involves large-scale cutting and filling. Built based on terrain features, these routes seamlessly blend...
into the natural scenery, crossing over valleys, mountains and hills along the way. Viewed from a distance, the motorways in this country look like ribbons winding through the green mountains and rivers. To avoid damage to the natural ecology of hilly sections, opposing lanes of traffic are separated; sections with picturesque scenery are generally left in their original state; planting and greening are generally carried out for filled hills, improving the landscape and reducing noise. Excavated sections generally have gentle side slopes with various local plants growing on the slope; masonry work is seldom performed to protect the subgrade.
Motorway landscaping in, for example, Italy, Switzerland and Austria is also designed to be visually appealing, as shown in Figure 7, Figure 8, Figure 9 and Figure 10.

Compared with the good motorway network in European countries and the USA, Asian countries have a relatively weaker network. However, Asia has experienced rapid development in recent years. Despite a land area of only just over 370,000 square kilometres, Japan boasts a modernized motorway network with a total length of 11,520 km. Based on its development plan, Japan will expand its motorway network to a total length of 14,000 km by 2015.
Figure 7  View from either side of a motorway in a suburb of Venice, Italy.

Figure 8  Scenery along a motorway in Zurich, Switzerland.

Figure 9  Corner of a parking area on a motorway near Vienna, Austria.
Japan’s motorways are designed in a rational manner concordant with the terrain features. Motorways are integrated with nature, reducing large-scale cutting and filling. Sometimes the two directions of the motorway are separated at varying heights, reducing excavation work without causing great damage or impact on the surroundings. In addition, Japan puts much emphasis on vegetation protection and restoration as well as natural landscaping in motorway construction. For example, biological protection techniques are adopted for filled, sloped and truncated sections. Trees, shrubs and herbs are all arranged in a natural and varied manner, and rubble masonry is seldom used. In recent years, Japan has adopted the following principles for the development of its motorway network: landscaping is incorporated into motorway construction and an appealing and convenient motorway network that is harmonious with nature along the route has been quickly established in order to satisfy people’s demands for a better quality of life. Thus we can see that Japan takes all factors of landscaping, ecology and environment into consideration simultaneously while designing and constructing motorways (Figure 11, Figure 12 and Figure 13).

Since the first motorway (the Shanghai–Jiading Motorway) was completed and put into operation in 1988, the Chinese mainland has also built the Shenyang–Dalian Motorway and the Beijing–Tianjin–Tanggu Motorway. In the space of less than 20 years, the total length of motorways in this country has increased from 18.4 in 1988 to 46 200 km in 2007, ranking second in the world. In accordance with the national motorway development plan, China will build a motorway network with a total length of 85 000 km by 2020.

After nearly 20 years of motorway development, China has begun to focus on motorway ecology and landscaping in addition to engineering standards. China specifies the requirements for ecological protection and environmental construction, requiring an end to irregular excavation, random construction
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Figure 11  Motorway landscape in Japan.

Figure 12  A service area of a motorway in Japan built on a hilltop.

and behaviour that destroys the ecological environment. Motorway construction is subject to the requirements of ‘ecological and environmental protection and landscaping’. In terms of afforestation, according to relevant authorities, green belts on both sides of motorways will be designed to protect the subgrade and side slopes, reduce soil erosion, restore the ecological environment and enrich the motorway landscape; greening of central reservations is designed to prevent glare, ensure safety and maintain a visually appealing view; the layout of interchanges focuses on using plants for landscaping, and environmental greening and landscaping work in service areas shall be strengthened to provide a comfortable environment for drivers and passengers. A scenic environment in harmony with nature can therefore be realized through landscape design.
Jiangsu Province is witnessing rapid motorway development at a rate of over 300 km per year and was the initiator of motorway landscaping in China. In 1999, Jiangsu issued *Guidelines for Jiangsu Motorway Greening Plan and Design* and *Technical Specification for Greening Construction*, so as to standardize motorway landscape design in the province and promote natural and ecological motorway design. For example, the Fenshui–Guanyun Motorway, completed in 2002, focuses on topographic renovation and is a perfect example of a motorway that has taken ecological factors into consideration. The Nanjing–Hangzhou Motorway, built in two phases, respectively, in 2003 and 2004, provides a high-speed connection between Nanjing, the capital of Jiangsu Province, and Hangzhou, the capital of Zhejiang Province. The motorway runs through a part of China reputed to be ‘Paradise on the Earth’, with a moderate climate, abundant natural resources, a splendid natural environment, strong cultural and historical heritage and a vast wealth of tourism resources. In the wake of further reform and opening up in China, this region has seen remarkable economic growth and plays a leading role in many sectors. The Party Committee, the provincial government and the provincial Ministry of Transportation required that the motorway should be built as the first ‘green motorway’ in Jiangsu integrating both ecological and environmental protection, landscaping and tourism.

To achieve this goal for the Nanjing–Hangzhou Motorway, the Jiangsu Motorway Construction Headquarters introduced the advanced motorway design concepts and methodologies from foreign countries to conduct landscape design according to international standards. With the introduction of the state-of-the-art ‘bead chain’ design concept and through elaborate design and construction, the completed Phase I of the project represents a well landscaped motorway integrated with the surrounding natural environment. Damage to the environment along the motorway was minimized in
construction, and therefore this noticeably improved the appearance of the surroundings.

The construction of the Nanjing–Hangzhou Motorway has significantly improved motorway construction in Jiangsu, and has played a guiding and demonstrative role for motorway landscape construction within and outside the province. It is important to study and summarize the advanced design concepts and adopt the advanced technologies and methods, so as to promote fully motorway landscape construction in Jiangsu Province.
1 Impact of Motorway Construction on the Environmental Landscape and Protection Countermeasures

1.1 Impact on the natural environment

Topography

Motorways are large-scale man-made projects. During their construction, the topography of the surrounding area will be subject to significant impact. For example, before the construction of the Nanjing-Hangzhou Motorway, the area was characterized by beautiful scenery (Figure 1.1). However, since its construction, great changes have happened to the local environment. First, the motorway has occupied a large area of arable land. During Phase I of the project alone, 4329.86 mu (about 288.66 hm²) of land and 2205.3 mu (about 147 hm²) of excavated land was requisitioned; there was a fill volume of 6.1732 million m³ and an excavation volume of 3.1279 million m³. As such a large area of cultivated land was requisitioned, the topography across the construction area of the surrounding area was subject to serious degradation (Figure 1.2), especially the areas of great natural beauty. For example, over 400 000 m³ of stone was excavated from the Donglushan Mountain in Lishui County, resulting in an 80 m high rocky slope surface (Figure 1.3). The construction of the motorway therefore resulted in heavy damage to the local environment. Of course, we can mitigate damage to the local environment by planting vegetation and covering the rock surface with plants, but it is difficult for the environment to revert back to its original condition and therefore destruction to the environment is irreversible. Data show that the area needed to construct a motorway is larger than an ordinary road or railway. In flat and hilly areas, the land occupation ratio of a motorway is usually 8.0~10.7 hm²/km. Table 1.1 shows the land occupation of the Nanjing-Hangzhou Motorway (Phase I).
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Figure 1.1  Picturesque scenery before construction of the Nanjing-Hangzhou Motorway.

Figure 1.2  Excavation resulting in destruction of the landscape.

Figure 1.3  Excavation resulting in a steep slope on the Donglushan Mountain.
Table 1.1  Land occupation area of the Nanjing-Hangzhou Motorway (Phase I) (unit: mu).

<table>
<thead>
<tr>
<th>Points of origin and destination</th>
<th>Township</th>
<th>Farmland</th>
<th>Commercial forest</th>
<th>Hilly land</th>
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<td>7374.7</td>
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1 mu is equal to ~666.67 m².

According to Table 1.1, the Nanjing-Hangzhou Motorway occupies an area of 11 808.4 mu (about 787.23 hm²), most of which is farmland and commercial forest, which amounts to 10 640.5 mu (about 709.37 hm²). As a consequence, it brought about not only a devastating effect on the local natural environment, but also had an adverse impact on local agricultural production and socio-economic development.

Soil erosion

Soil is one of the most important factors for the growth of vegetation along a motorway. During motorway construction, quarrying, borrowing earth and spoil grounds will cause soil erosion. The fertility of soil is reduced, changing its physicochemical properties, which makes it more difficult for vegetation to grow and recover. If the soil structure of the land under construction changes due to compaction from machinery or the land being trampled on, the fertility of the soil may not recover for a long time.

Soil erosion destroys the vegetation along a motorway. In turn, the loss of vegetation further exacerbates soil erosion. This vicious circle makes it very difficult for the vegetation to grow and recover. On the other hand, soil erosion causes change in topography, resulting in water and soil loss (Figure 1.4). According to a survey, water and soil loss resulting from motorway construction in Guangdong Province reaches 4.6203 million m³ every year. For example, during the construction of the Ningxia Guyaozi–Wangquanliang Motorway, the area affected by water and soil loss increased by 592.48 hm². This was due to disturbing the original topography and damage to the soil
and vegetation. Of the 592.48 hm² affected, cultivated land amounted to 134.20 hm², woodland 152.10 hm², grassland 295.75 hm², and other land 10.43 hm². For soil erosion on the Nanjing-Hangzhou Motorway, see Table 1.2.

According to Table 1.2, the construction of the Nanjing-Hangzhou Motorway has resulted in serious soil erosion.

Climate

Upon construction, motorways can generate a microclimate environment, which mainly depends on the properties of the underlying surface and the
composition of the atmosphere. A motorway microclimate that is adverse to plant growth has the following features:

1. **Cold.** Motorways are generally far away from centres of population, with high subgrades, spacious topography and fast air convection. Particularly on interchange sections, the clearance under the bridge is relatively high, resulting in freeze injury to trees on windward slopes in North China. In the winter of 1997, one-third of Chinese Juniper in the central reservation died or was affected by frostbite due to the wind beside the approach of Shahe Grand Bridge 233 km along the Beijing–Shijiazhuang Motorway.

2. **High temperature.** At either side of the central reservation, there is a 10-m-wide black paved surface. During the summer, the air temperature can reach roughly 40°C, but after factoring in the thermal radiation of the black pavement, the local air temperature may reach over 50°C in some areas.

3. **Drought.** Due to the thermal radiation of the black pavement, the high temperature exacerbates the evaporation of soil moisture and the transpiration of trees, resulting in the death of trees due to drought. This phenomenon is even more apparent in the central reservation.

4. **Strong gale.** Motorways feature high subgrades, spacious topography and fast convection. High-speed vehicles increase the wind speed, especially large buses, which may produce an instantaneous wind speed of 25 m/s. This is a very common occurrence, which causes the trees to sway wildly, resulting in damage to their root systems and exacerbation of water loss and drought.

**Hydrology**

In motorway construction the direction of surface water may often change its course. Due to the diversion of the river flow, water and soil loss worsens at areas where the flow of water is concentrated and erosion occurs where the structure of the water flow is adverse. In river or wetland areas, it is necessary to change the original direction of the river when a motorway is built. After the direction of the river has been changed, a very large flow is generated in areas where many waterways come together and the flow rate speeds up. The hydrological conditions then change, resulting in floods, a worsening of water and soil loss or an increase of downstream silt (Figures 1.5 and 1.6). The area where the Nanjing-Hangzhou Motorway (Phase I) was built is in the Qinhuai River basin. Along the route, there are low mountains, hills and flat areas as well as numerous big and small lakes and crisscrossing rivers. Most of the waterways that the Nanjing-Hangzhou Motorway passes over are barge routes and irrigation channels. Although the aim was to minimize and avoid adverse effects during bridgework, culvert design and subgrade construction, elements
Vegetation

The impact of a motorway on vegetation mainly refers to the direct impact of land destruction, borrowing earth and spoil grounds during motorway construction, as well as the indirect impact of motorway traffic. The former is transient and irreversible; the latter is more long-term and reversible. During motorway construction, direct destruction of vegetation mainly stems from the following two aspects: permanent destruction from site clearing, and damage from the temporary spoil ground and construction road. For example, the land permanently occupied by the Jilin–Changchun Motorway project is 571.8 hm², of which dry farmland accounts for 76.5%,
paddy fields 12%, uncultivated land 1.9% and woodland 9.6% (19,360 timber trees were felled). According to calculations, the amount of carbon dioxide absorbed annually by the vegetation has decreased by 8,274 t and the amount of oxygen released annually has decreased by 6,040 t. Due to the occupation of cultivated land, the amount of oxygen released annually has decreased by 1,500–5,000 t. Using Zhoukou–Shengjie (Provincial Boundary) Motorway in Henan as an example, the 9.498-km-long section within Beijiao Township, Shenqiu County alone covers a cultivated land area of 69.8 hm², equal to a vegetation damage rate of 1.968%. As a large amount of cultivated land has been occupied, farmers may cut down woodland to make up for the occupied land, further worsening the damage to the vegetation along the motorway (Figure 1.7). After the completed motorway was opened to traffic, pollution from vehicles has also been an indirect factor contributing to vegetation damage. It is reported that farmland within a range of 50 m of both sides of the motorway has seen an average reduction in output of 15% due to dust and exhaust fumes from trucks transporting coal from Shanxi Province to other regions. As a result, the wheat yield in the province has decreased by 28.13 million kg every year, equal to a loss of RMB 33.75 million.

Of the land requisitioned for the Nanjing-Hangzhou Motorway (Phase I), arable land amounts to 150.02 hm², commercial forest 50.17 hm², hilly land 22.68 hm², borrowed land 147.02 hm², as well as extra temporary land use for the construction road, mixing yard, prefabrication yard and construction camp. The vegetation at these places was cleared during construction. After completion of the project, new vegetation was planted over an area of 909,029 m², accounting for 20.76% (6535.16 mu or ~436 hm²) of the total land requisitioned. In other words, the Nanjing-Hangzhou Motorway (Phase I) resulted in a loss of green vegetation of 271.90 hm² (Figure 1.8) to this area; it was therefore inevitable that the local environment would be affected.

![The motorway occupies the local tea plantations and woods.](image-url)
Wildlife

Wild animals are the main victims of habitat fragmentation during motorway construction. As the forest decreases in size and is divided by residential areas and traffic networks, their habitat gradually shrinks. These small habitats are not sufficient for the animals to survive. If their territory is too small, they cannot acquire enough food, resulting in the decline or extinction of these animal populations. Increased traffic flow and expanding human activity also reduces their habitats, affecting their mating and reproduction, further aggravating the impact on them. In addition, newly built motorways directly cause a loss of habitat and terrain features, resulting in a change in climatic factors such as sunlight, wind speed, temperature and humidity. Meanwhile, vibration, noise, atmospheric pollution and soil pollution from vehicles has a negative impact on the survival, reproduction and migration of local plants and animals.

According to a survey, there are fewer wild animals and species in areas next to the Nanjing-Hangzhou Motorway (Phase I), including species such as wolf, boar, vole, hedgehog, yellow weasel, rabbit and common birds. Although the construction of the motorway has resulted in adverse impacts on such wildlife, the consequences are not too severe as there are no rare or state-protected species in the region.

1.2 Impact on history, culture and scenery

If the route is not selected carefully or if no attention is paid to conserving water and soil during construction, there may be the following problems:

(1) The motorway passes through a town.
(2) It passes through a scenic spot.
(3) It goes through a forest.
(4) Mountains have to be cut into and deep holes must be filled.
(5) The flow of the river changes and streams become blocked.

Poor route selections such as these not only damage the ecological environment across the region but also the integrity of the history, culture and scenery in the area, as well as the regional tourism resources. A survey has found that there are no cultural relics and scenic spots requiring special protection along the Nanjing-Hangzhou Motorway (Phase I), so the impact on the history, culture and scenery of the area along the motorway has been small and the prospect for the development of tourism resources is promising. Phase II passes by the Longbeishan Mountain National Forest Park but does not go directly through it, so its impact is negligible. The completed Nanjing-Hangzhou Motorway serves as a protective barrier for the Longbeishan Mountain National Forest Park, protecting it against the erosion of land for urban development.

1.3 Pollution of the surrounding environment

Motorway construction has polluted regions along the route to a different degree.

Noise pollution
There are two kinds of noise pollution: one is from excavators, bulldozers, land levellers, lorry mounted mixers and other types of construction vehicles. These vehicles and equipment create significant noise pollution. For example, the noise from a common road building machine exceeds 80 dB, while that from a pile driver is higher than 100 dB. The other kind of noise pollution is from traffic, forming a noise belt along the motorway route. The noise from these sources has a negative psychological and physiological impact on constructors and people in the surrounding areas. It also reduces people's work efficiency, having a particularly apparent impact on sensitive areas with a high population density on both sides of the motorway (schools, residential areas, commercial districts, hospitals, etc.). At nighttime, the noise affects the lives of people living alongside the motorway and the impact will only worsen in the future (Figure 1.9).

Water pollution
There are two sources of water pollution from the motorway: one is from subsidiary facilities along the route, such as service areas, toll stations, management centres and maintenance work zones. In general, a motorway can produce about 200 000 t of sewage a year. After treatment, the sewage can
The Environment and Landscape in Motorway Design

Figure 1.9 Residents on both sides of the motorway will be disturbed by noise.

Table 1.3 Predicted value of the concentration of pollutants in the surface runoff.

<table>
<thead>
<tr>
<th>Item</th>
<th>SS</th>
<th>BOD5</th>
<th>Petroleum</th>
<th>CODcr</th>
</tr>
</thead>
<tbody>
<tr>
<td>120 min mean value (mg/l)</td>
<td>100</td>
<td>5.08</td>
<td>11.25</td>
<td>107</td>
</tr>
<tr>
<td>Quantity of pollutants discharged (t/a)</td>
<td>2977.8</td>
<td>15.1</td>
<td>33.5</td>
<td>318.6</td>
</tr>
</tbody>
</table>

meet effluent standards, that is CODcr 100 mg/l, BOD 530 mg/l, SS 70 mg/l and petroleum 10 mg/l. However, this waste water will result in water pollution if discharged into a river or a lake. If the waste water is not treated or if treatment is not complete or does not meet the necessary standards, the resulting water pollution is more severe and harmful.

The other source of water pollution is pollutants from automobile exhaust fumes, surface residues and surface materials. These pollutants flow across the surface of the road into reservoirs and rivers after rain, contaminating these areas to a certain degree. In the region where the Nanjing-Hangzhou Motorway (Phase I) is located, the mean annual precipitation is 1050 mm, and the total area of pavement is 2.836 km², therefore the annual surface runoff volume is 2 977 800 m³; the total discharged quantities of all types of pollutants are shown in Table 1.3.

Atmospheric pollution

The main cause of air pollution is automobile exhaust emissions, including carbon monoxide (CO), nitric oxide (NOx), total hydrocarbons (THC) and total suspended particulates (TSP), of which NOx is the most serious pollution to the environment, followed by CO and THC.

After the Nanjing-Hangzhou Motorway was completed there was an increase in NOx emissions because vehicles started to travel much faster. The motorway does not pass through urban areas, thereby reducing congestion on urban roads and relieving air pollution of cities along the motorway.