Vulnérabilité du système routier chinois à l'égard des changements climatiques

Qingquan LIU, Erhu YAN, Dongchang DAI
Institut de Recherche des Routes, Ministère des Communications, R.P.Chine
qq.liu@rioh.cn, eh.yan@rioh.cn, dc.dai@rioh.cn

RESUME

L'infrastructure routière chinoise forme déjà un système très étendu qui joue un rôle important pour réduire les problèmes d'encombrements du transport à l'égard de l'économie nationale, et contribue efficacement au développement économique et social de la Chine. Cependant, la Chine connaît des changements de climat qui ont des effets défavorables sur le système routier et en révèlent sa vulnérabilité. Cette communication présente les changements du climat en Chine, principalement l'effet de serre et les phénomènes extrêmes météorologiques plus fréquents, ainsi que les dommages provoqués par ces changements au système routier. Enfin, ce dossier présente les mesures adoptées par le ministère chinois des routes pour contre ces changements.

Texte en anglais

1. OVERVIEW OF CHINA'S ROAD SYSTEM

China's road system has kept continuous and rapid growth since reform and opening up in 1980's. Fig.1 shows the growth of road mileage and investment in road construction over years since 1998 and Fig. 2 demonstrates the growth of expressway mileage. Fig 3 and Fig. 4 describe the technical and administrative classifications of road network in 2005 respectively. Statistics by the end of 2005[1] indicated that road mileage in mainland China had reached 1.9305 million Km, with road density of 20.1Km/100km^2. The total mileage of paved roads and simply paved roads was 994600km, accounting for 51.5% of total mileage. If classified by pavement type, the mileage of paved road was 532697Km, including asphalt concrete of 226075Km and cement concrete of 306622Km, simply paved road of 461901Km and unpaved road of 935945Km.

Above statistics indicate that China's road infrastructure has basically formed as an extensive system, which played an important role to alleviate the "bottleneck" constraint of transportation on national economy and enhanced greatly economic development and social progress in China. Meanwhile, the infrastructure has already become a huge social wealth. Nowadays, people depend irreplaceably on the road system for economic activities and daily life. Temporary disruption of even a small stretch would cause great inconveniences to users. On the other hand, the bigger the system is, the more the maintenance cost and difficulties would be. Roads are exposed to natural elements, like sunshine, rain, dew, ice, snow, wind, frost, etc. The destruction of road is sometimes inevitable due to the nature's prowess. As a result, we would lose social wealth and have more difficulties in maintaining road system. Hence, how to respond to destruction of climate changes on road system is an arduous task that we are facing.

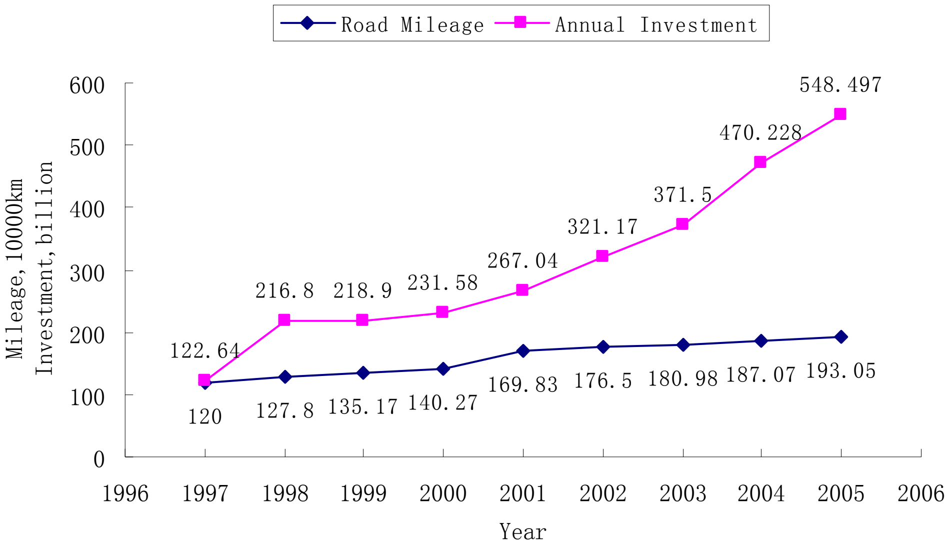


Fig.1- Growth of Road Mileage and Annual Investment in China

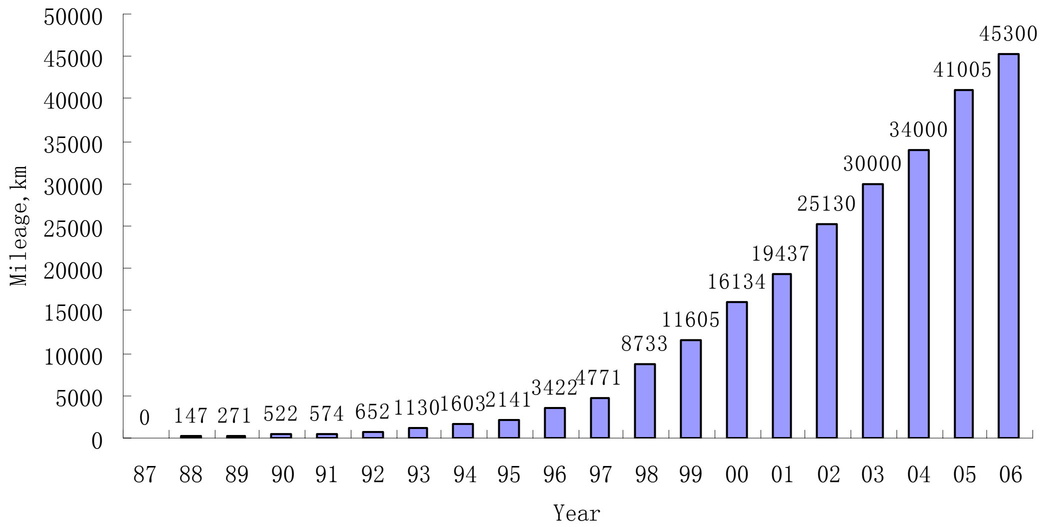
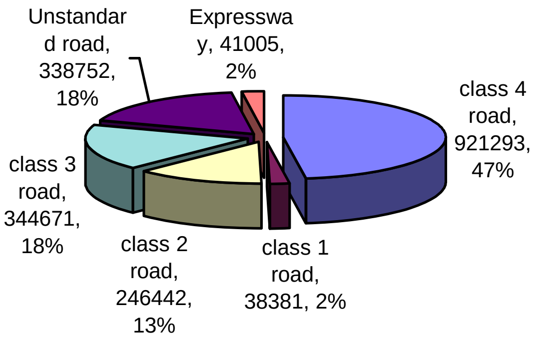


Fig.2- Growth of Expressway Mileage in China



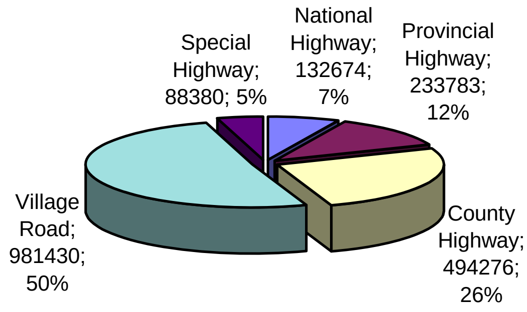


Fig.3- Technical Classification (km)   Fig.4- Administrative Classification (km)

2. MAJOR METEOROLOGICAL CHANGES AND INCIDENTS IN CHINA

China is mostly in the monsoon region and is a typical country of monsoon climate. In recent years, climate elements have been changing obviously. As the consequence, China has been suffering from a variety of widespread meteorological disasters with high frequency. The primary phenomena of climate change in China since 1980's has been warming and frequent occurrence of extreme weather incidents such as heavy storm, and typhoon.

2.1 Trend of warming

China is one of the countries with most distinct features of global warming. According to the third assessment report of IPCC[2], the average temperature raised by 0.6±0.2ºC from 1860 to 2000, and the 1990's was the warmest decade in the 20th century. Under the backdrop of global warming, China's annual average temperature increased by 0.65±0.15ºC in last century, slightly higher than global average temperature rise in the same period. Fig. 5 shows the annual temperature changing since 50's last century in China from which we can see that in about half century's time the temperature is significantly going up, particularly after the year of 1985. Since the winter of 1986/1987, China has experienced 19 warm winters (only the winter of 2004/2005 is normal). In 2006, China's annual average temperature was 9.92 ºC, recorded the warmest year since 1951. And in the same year, 17 provinces(cities and regions), located between Yellow River and Nanling Mountain, had the highest annual average temperature since 1951.Regions with most distinct temperature rise in past half century include North China, east of Inner Mongolia and Northeast China. It shall be particularly noted that record-breaking temperatures were measured in 13 stations amongst 39 state official meteorological observations on Qinghai-Tibet plateau that are extremely sensitive to climate.

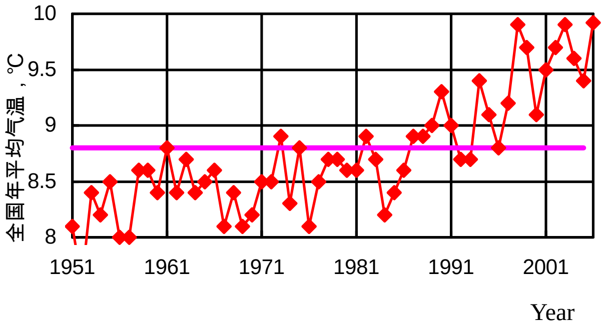


Fig.5-Changes of Annual Average Temperature in China

As forecasted based on climate patterns and compared with 2000, annual average temperature in China will increase by 1.3~2.1ºC by the year of 2020, and 2.3~3.3ºC by 2050. Global warming is already an undisputable fact. In the predictable future, we can't see a clear trend of alleviated global warming yet.

Global warming is the macro-background of extended time dimension. But, the direct element that controls occurrence frequency and strength of extreme heat waves each year is abnormal atmospheric circulation. Nationwide extreme high temperature is mainly caused by somewhat weak activities of cold air from the north, northward movement of the western Pacific ridge line of the subtropical high, stable high pressure of the continent and somewhat less snowfall on plateau in winter. Since 1990's, extreme incidents of scorching weather occur frequently, featured of extensive area, high frequency and intensity.

Formerly, the hottest regions in China were in Southern area and along Yangtze River. But in recent years, regions at high and medium latitude in China have been suffering from increasingly hot climate. North China has become gradually a new high-temperature zone among others. Fig. 6 depicts the distribution of extreme high temperature in mainland China, from which we can see that most of provinces influenced by high temperature above 37ºC except for Tibet and Qinghai. And mainly the high temperature influenced provinces are those of dense populated and developed ones in East and Central China. Most parts of 13 provinces (municipalities), some parts of 11 provinces and some cities in three provinces among 33 provinces of the country suffered from high temperature above 40ºC.

From 1949 to early 1990's, serious high temperature weather occurred twice in China (1978 and 1988). Since 1990's, heat waves weather has been frequently occurring in summer. The extreme temperature records in 2003 and 2006 were rare in the history for its high intensity, widespread influence and long duration. Since 1999, more than ten days of extreme high temperature weather may occur in North China, Yangtze River valley and its south, and eastern part of Northwest China every year.

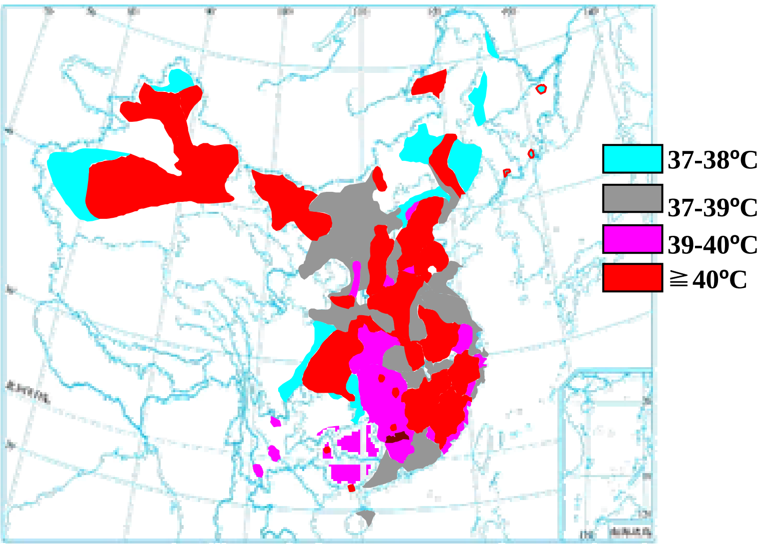


Fig.6- Distribution of Extreme High Temperature in Mainland China (≥37°C)

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In recent years, there are more than twenty observatories in China who measure record-breaking high temperature almost every year. Table 1 lists the yearly highest temperature of some cities from 2001 to 2006 and the maximum in recent 35 years. It can be seen that the maximum values of yearly highest temperature in past 35 years were recorded in recent five years, and in fact, most of them are the highest in the past half century or the whole century.

Table 1 - Extreme High Temperature in Major Cities in China

City	2001	2002	2003	2004	2005	2006	Maximum 1971-2006	Region
Nanjing	38.3	39	40	38.7	37.3	37.9	40	East China
Hangzhou	38.1	38.3	40.3	39.6	39.3	39.3	40.3	
Shijiazhuang	40.8	42.8	38.5	37.9	41.9	38.8	42.8	North China
Jinan	37.6	42	37.7	36	40.8	38	42	
Xian	40	40.1	39.2	39.4	41.7	42	42	Central China
Zhengzhou	39	41.7	37	39.7	40.4	40.1	41.7	
Wuhan	38.2	38.7	39.6	37.8	38.3	37.5	39.6	Central South China
Changsha	38. 2	38. 8	41	38.5	38	38.5	41	
Chongqing	40	38.5	40	41	38.9	43	43	Southwest China
Turfan	47	45	43	46.2	45.6	47.7	47.7	Northwest China

While the yearly highest temperature goes up, the duration follows the same upward trend. For instance, while the yearly highest temperature in Chongqing from 2000 to 2006 updates consecutively, the duration of such high temperature lasts from five or six days to forty days. Especially in 2006, more than 37ºC scorching days lasted nearly two months in Chongqing from 11th of Jul to 3rd of Sep.

Global warming results in elevation of sea level, melting of glaciers and thawing of frozen earth. In recent half century, the area of frozen earth in entire northern hemisphere has been reduced by 3~4 million km^2. Along with global warming, permafrost degrades obviously, seasonal frozen earth thaw fast, and melting sink goes deeper. Qinghai & Tibet Plateau is a permafrost region of highest elevation and most extensive distribution in the world. Concerning to this permafrost, the temperature was increased by 0.5~ 1.5 º C and the active layer was deepened by about 1m over past 50 years. The permafrost area in whole China has been reduced by 10%~15% in recent 50 years.

2.2 Frequent occurrence of extreme weather incidents

Since 1990's, larger and larger area has been hit by weather calamity. During 16 years from 1990 to 2005, there were eight years in which we had more than 50 million hectare of territory inflicted by disasters. Table 2 lists the area influenced by weather disasters in different periods, from which we can see the growing trend. Fig. 7 shows the percentage of areas hit by major types of weather disaster in China in 2005, from which we can see that the area inflicted by drought and flood accounts for about 70%[4].

Annual average precipitation in China in the past century didn't change apparently. Occurrence of drought or flood was caused by disequilibrium of precipitation among regions. If south and north region is roughly divided by Yangtze River and Huai River, more precipitation has taken place to the south than to the north since 1980's. The precipitation along Yellow river valley is reduced by more than 15%. Since 1970's, the lower reach of Yellow River has often been dried up. The most serious occurrence was in 1997. As affected by drought, the Lijin Hydrological Station on downstream witnessed 226 days of no flow that year and the longest dried-up river section was more than 700Km. It is this regional change of precipitation that results in persistent drought in the north and frequent occurrence of flood in the south. Drought is less destructive to the road system, but flood always cause serious damage to roads and bridges. According to statistics, about 2/3 of land area in China is inflicted by waterlog to different degrees and waterlogged area reaches about 8.93 million hectares each year.

Table 2 - Areas Influenced by Weather Disasters in Different Periods (Unit: 10^4 hectare)

Period	1950～1959	1960～1969	1970～1979	1980～1989	1990～1999	2000～2005
Area	2192.1	3446.4	3791.3	4152.1	4934.3	4740.8

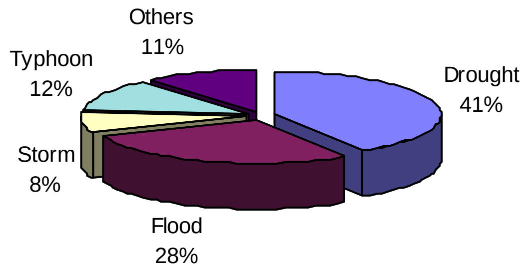

Fig.7- Percentage of Areas Hit by Different Weather Disasters

Besides disasters of storm and flood, some areas in the south are also inflicted by tropical cyclone, with increasingly higher frequency and greater loss. Taiwan, coastal area of South and East China are regions which are most frequently and seriously attacked by typhoon in the world. The high frequency of tropical cyclones in the above area is even rare in the world. There are about 80 tropic cyclones taken place each year with maximum wind force at or above 8 degree around the center. Most of them, i.e. 35%, occur in Northwest Pacific. Averagely, about 6.9 tropical cyclones landed on Chinese coast each year, of which, 4 would be the disaster ones. As an unordinary case, there are eight fierce typhoons landed in succession in 2005, and the total losses were up to 81.5 billion in RMB. Typhoon was the top natural disaster in China that year.

3. INFLUENCES OF CLIMATE CHANGES ON ROAD SYSTEM

Since 1960, the number of major natural disasters occurrence has been tripled and insurance loss been increased by fifteen times in fact. 35~40% of most devastating disasters are related with climate changes. Economic losses caused by climate disasters each year is about RMB200 billion, accounting for about 3% to 6% of GDP, equivalent to 10%~20% of GDP increment[5]. Population influenced by climate disaster each year was about 380 million person times. Table 3 shows economic losses caused by natural disaster each year from 2001 to 2006 in China, of which above 70% caused by climate disaster. According to the 15-year statistics from 1990 to 2004, average economic loss caused by climate disasters in China was RMB176.2 billion each year, in particular, RMB300.7 billion in 1998.

Table 3 - Economic Loss Caused by Natural Disasters in China from 2001 to 2006

Year	2001	2002	2003	2004	2005	2006
Direct Economic Loss (100 million)	1942.2	1637.2	1884.2	1602.3	2042.1	2528

Road loss is of a high percentage among all economic loss caused by climate disasters. China has a huge road system, which is vulnerable to climate changes, and faces tremendous challenges. Each year, climate changes cause widespread cutoff and destruction of road system, which demand intensive efforts of maintenance, rehabilitation or even reconstruction, and hence huge economic loss.

3.1 Influence of heat wave on asphalt roads

Heat wave is mainly destructive on asphalt pavement. Although asphalt roads are only 226075 Km long and 11.7% of total mileage in China, it is the most important part in China's road system. Asphalt pavement is the major type of structure for trunk roads and expressways in China and more than 95% of expressway is asphalt-paved. Fig. 8 shows the percentage of expressway mileage inflicted by local extreme high temperatures to the total mileage, from which we can see the influence of extreme high temperature on expressway.

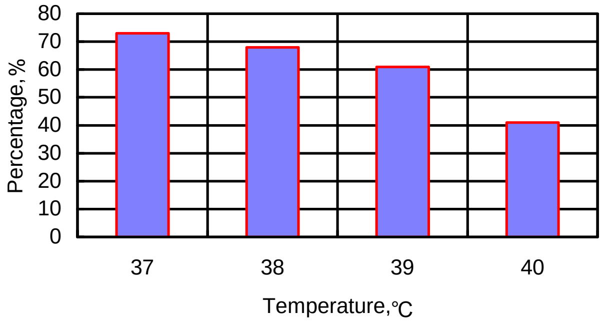

Fig.8- Percentage of Expressway Influenced by Extreme Temperature

Asphalt mix has large capacity of heat absorption. Therefore, road surface temperature is always higher than air temperature by 20ºC~30ºC. On the other hand, asphalt mix is quite sensitive to high temperature. As temperature goes up, permanent deformation increases rapidly, following an exponential order. Especially when the temperature is in range of softening point ±3 ºC, the deformation of asphalt mix increases greatly. The most consistent feature of rutting in many roads is that they all occur in scorching period. Investigations reveal that deep rutting seldom occurs when the temperature is lower than 30ºC (the surface temperature is lower than 50ºC), while rutting increases rapidly when the temperature exceeds 37ºC (or the surface temperature is above 57ºC). If the temperature is beyond 40ºC (surface temperature is above 60~70ºC), serious rutting damages would occur within a few days. It is commonly believed that the deformation of asphalt mix will be doubled for every 5ºC of temperature increment, i.e. the deformation will increase by 20% for each 1ºC of increase. The asphalt pavement damage could be formed in very short time. Serious rutting could occur on many expressways only after two hot seasons after opening to traffic. Moreover, rutting could develop in some section of road after a summer or even in less than one week's time when the temperature is high enough. After one summer, the average rutting depth would reach 1~2cm, or even 5~8cm under extreme conditions.

In addition to rutting, bleeding, waving, swelling and other types of structural damages could be brought about by heat waves, which shorten the lifespan of roads. It is reported that the lifespan of asphalt road could be shortened by 20~30% due to high temperature, overloading and other factors, and moreover, the lifespan could be shortened even by 50~60% on steep and long upslope stretch of road. Economic loss directly caused by heat waves could reach above RMB10 billon each year. Furthermore, congestion and detour caused by restoration bring about inconvenient to users and results in negative social effect.

3.2 Influence of gradual temperature rise on roads in frozen earth area

Degradation of frozen earth caused by sweeping progressive temperature increase could influence directly and threaten the foundation stability of roads, bridges, culverts and other structures. Hence, roads in permafrost region would be damaged somewhat each year. The common phenomena of damage in permafrost region include sedimentation, swelling and frost boiling.

Qinghai, Tibet and Heilongjiang all suffer from road damages due to degradation of permafrost earth. The permafrost mileage in the section of State Highway No.109 from Xidatan to Anduo, which was 545Km in 1985, was shortened by 16.5Km in 15 years. According to the study and forecast made by State Key Laboratory of Frozen Earth Engineering, China Academy of Science, the permafrost earth in the section from Erlashan to Qingshuihe of State Highway No.214 will be degraded from 92Km (1992) to 53.8Km, with a ratio of 41.5%. The range of discontinuous permafrost earth will be reduced from 147.3Km to 38.2Km, with a degradation ratio as high as 74.1%. Due to lack of understanding on degradation of permafrost earth, Qinghai-Tibet Highway was reconstructed for three times from 1973 to 2003. The road of 2412km has been reconstructed for exactly 30 years. Up to now, some sections of the Highway still need to be repaired each year due to the influence of frost earth【6】.

As for high-grade roads paved with asphalt mix, the frost earth's original water &heat exchange balance would be destroyed due to heat absorption and water sealing on the surface, which results easily in higher possibilities of thawing sink. The road section of Xining-Kurlur that is a part of State Highway No.227 completed the upgrading to Class III with asphalt pavement in 1999. Only two years latter, was sinking induced by thawing on large scale. The total sinking mileage was 18Km, and the thawing-sink area is about 1/3 of total area with the deepest sink up to 80cm【6】. As for low-grade roads, the damage caused by degradation of frozen earth is mainly the frost boiling.

3.3 Damages of heavy storm and hurricane

According to statistics, direct economic loss of floods has been averaged around RMB110 billion each year since 1990, accounting for about 2% of GDP of the same period. In years of valley-wide deluge, for instance 1991, 1994, 1996 and 1998, the loss could reach 3%~4% of GDP. In 1998, twenty nine provinces (regions and municipalities) in mainland China were inflicted by floods in which eleven were seriously inflicted, incurring direct economic loss of RMB255.1 billion. Floods may be a cataclysm washing off road bank, destroying bridges, culverts and their accessory structure, causing pavement subsidence, cracking or other distress. Land slide and debris flow induced by flood are top natural disasters for roads over years in China.

Fig. 9 illustrates the mileage of roads damaged by floods in years from 1992 to 2005. Generally, the percentage of road damaged by floods each year was between 6.3% to 9.9%. The waterlogged area in 1998 set the record, and accordingly, the percentage of mileage of roads damaged by floods was the highest. The decreasing percentage after 1988 was due to increase of road mileage. While, the damaged mileage in 2005 reached 140000km, the highest in the history. Most roads destroyed by floods are unpaved low-grade roads, such as village road or county road.

Many roads are damaged by floods every year, which cause tremendous economic loss. Take Yunnan Province as an example, the annual direct loss caused by flood in Yunnan from 1986 to 1990 was RMB30 million, more than RMB100 million in the period of 1991 to 1995, and up to around RMB200 million from the year of 2000 to the present day. In 2003, accumulated losses from roads damaged by flood in Shan'xi province reached RMB350 million. In Anhui province, the condition of rural roads in regions along Huai River retrogressed by ten years after suffering from the flood in 2004. The total loss that year in transportation sector of Anhui was about RMB1.6 billion, Again, the flooding caused loss was up to RMB500 million the next year in Anhui. In early 1980's, economic loss from roads damaged by floods was averaged above RMB1 billion each year. Since 1990's, however, the loss has reached RMB5~15 billion per year. In 2005, China was attacked by eight fierce typhoons and more than twenty provinces and regions suffered from natural disasters of torrents, debris flow, collapse and landslides etc, As the result, 20000Km subgrade and 4000 bridges were destroyed, causing nearly RMB10 billion direct economic loss. From Jan. to Sep. of 2006, 8956Km of road subgrade, 24736Km of pavement and 2583 bridges were destroyed by floods, brought about direct economic loss up to RMB6.3 billion.

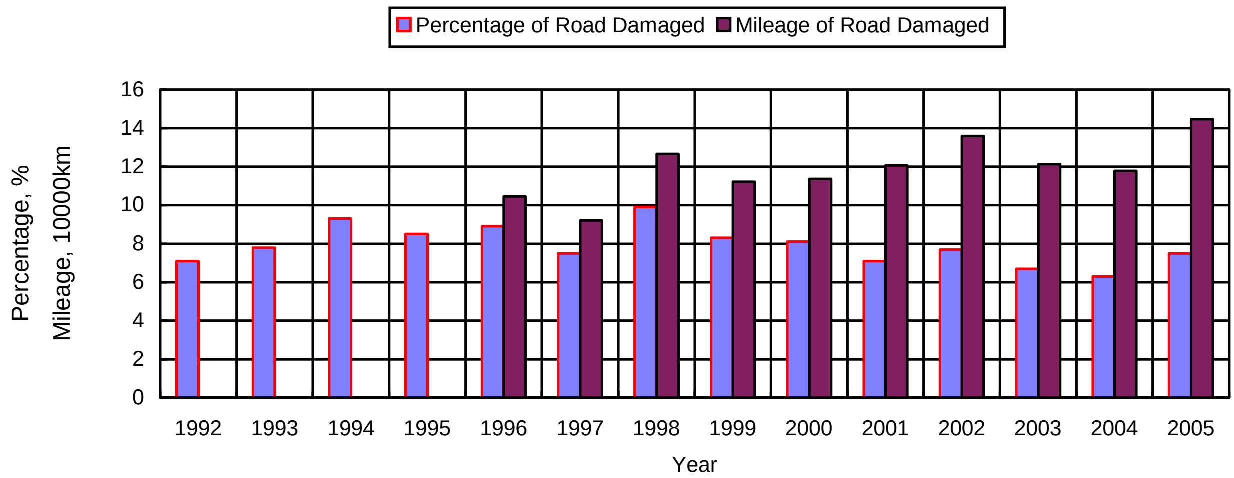

Fig.9- Mileage of Flood Damage from 1992 to 2005.

4. COUNTERMEASURES

China's annual revenue of road maintenance fee is about RMB90 billion but only about 60 billion is earmarked for road maintenance, while we needs at least RMB100 billion per year for existing road system maintenance in normal condition. To make things worse, direct economic loss of road damage caused by climate changes is as high as RMB20 billion per year in average. We are facing tremendous pressure due to the financing shortage for road maintenance. As a road engineer, maybe we can do nothing to climate changes and occurrence of extreme weather, but, at least we can try our best to improve road system's adaptability to climate changes in road design and construction to reduce the loss. In fact, we have already started this work.

4.1 Forecast on extreme weather

In China, the transportation authorities have already launched a cooperative program with weather departments to establish a Nationwide Weather Information Center for timely forecasting of weather along roads. While forecasting extreme weathers like high temperature and floods and trying its best to improve roads' anti-disaster capacity, the Center also provides guiding service to public for safe and convenient traveling.

4.2 Improve the stability of asphalt pavement at high temperature

Scorching weather is not the only reason for rutting, Overloading and low speed heavy-duty trucks on upslope stretch are also causes. In terms of road design, improper choice of asphalt mix types and asphalt grade could also weaken the adaptability to weather changes. For new asphalt pavement, the following proactive measures should be taken:

1) Research and develop new materials, new structures and new technologies to against heat waves. Promoting the application of modified asphalt, low-grade asphalt (i.e. 50#, 30#), natural asphalt (rock or lake asphalt) and other hard asphalt in high-temperature regions. The study on high modulus asphalt concrete is underway in many provinces.

2) The pavement structure design for long upslope subject to slow traffic of heavy-duty trucks has aroused attention. It is recommended to raise the design standard and to conduct specific designs for special section.

3) Further improve Chinese specifications for pavements in view of increasingly fiercer heat waves in the future, speed up the establishment of a multi-index system for pavement structure design, especially the rutting and permanent deformation indexes at high temperature.

4) As for asphalt roads in service, relevant departments are investigating into the possibility of heat wave forecast, load and traffic controls during high-temperature hours and cooling by water sprinkling as well. In scorching summers, limiting heavy-duty trucks to travel at cool nights could greatly relief rutting. We will carry out detailed study and assessment on forecast of high temperature. Furthermore, the information publishing mode, influence on road users, the society's acceptability and the reduction of road loss from these traffic control measures will be studied and appraised.

4.3 Technical measures to protect permafrost earth

The degrading trend of frozen earth is obvious along with global warming. To cope with the situation, we have fulfilled several research programs on road building techniques in permafrost region.

Firstly, geological reconnaissance and all-year-round observation on frozen earth have strengthened. The investigation was made on distribution and type of frost earth and evolvement patterns by using physical geography reconnaissance techniques, which provided basis for road design and construction. When the lay out is unavoidable on permafrost earth, protective measures should be taken to diminish the influence on frozen earth as much as possible.

Secondly, taking the influence of warming on frozen earth into account adequately in the aspect of design and construction, the design principle of "protecting frozen earth, controlling thawing speed, strengthening the subgrade side protection and comprehensive treatment" was put forward. The design philosophy of "voluntary cooling plus thermal isolating" was also proposed. The fulfilled studies indicate that reasonable selection of following measures is quite effective in protecting frozen earth: increasing the subgrade height, decreasing the vertical geothermal gradient, less-steep sloping of embankment, improving drainage facilities, using appropriate embankment stuffing, providing roads with ventilated banks, applying ventilated pipe or insulation layer, substituting road with bridges, using sun shields and sheds etc.

4.4 Countermeasures to flood disasters

Flood damage to roads is not a new issue, but an old one aggravated by climate changes. The occurrence of water damages isn't an isolated incident and must be treated in a comprehensive way, which includes engineering and biological treatment and environmental protection.

Most roads destroyed by floods are low-grade ones many of which are unpaved or simply paved roads. Poor quality, improper maintenance, destroyed green belt along roads and incomplete anti-flood facilities are direct causes to the flood damaged. Riverbed being encroached or compressed by roadbeds along riverside to some extent is also important reason for occurrence of water damages.

To prevent water damages, the following measures have been adopted:

1) Upgrade technical condition for county or village roads gradually by reconstruction, pay attention to hydrological survey and hydropower calculation in view of the entire route, strengthen the design of drainage and anti-flood structures, perfect drainage facilities, and improve the standardization of trunk roads and overall anti-flood capacity.

2) Strengthen road maintenance, change emergent repair into prevention, investigate into status quo of water damages during routine maintenance, carry out thorough cleanup and dredging before flood seasons, repair anti-flood structures, work out feasible guarantee plans for grand and medium-scale bridges vulnerable to flood damages, strengthen them at appropriate time, and prepare emergency plans for sections subject to frequent flood damages.

3) Work out annual treatment plan for road sections subject to frequent flood damages, and thoroughly treat them one by one to prevent reoccurrence of flood damages.

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