# 3. GEOLOGY

## 3.1 Introduction

### 3.1.1 General

Geological investigations for the Three Gorges Project have been in progress since the 1950s and are still continuing. Most of the work has been done by YVPO with the collaboration of a large number of agencies and research organizations. The scope of the work has been comprehensive, covering all aspects of reservoir geology, regional tectonics and seismicity as well as studies relating to site selection and structure foundation conditions.

Following a preliminary review of the available data, it was evident that the volume and quality of work accomplished was more than sufficient to satisfy feasibility requirements. Accordingly, CYJV studies have been based on the available documentation, supplemented by a number of site visits, including one tour of the reservoir area to review regional geology and slope stability.

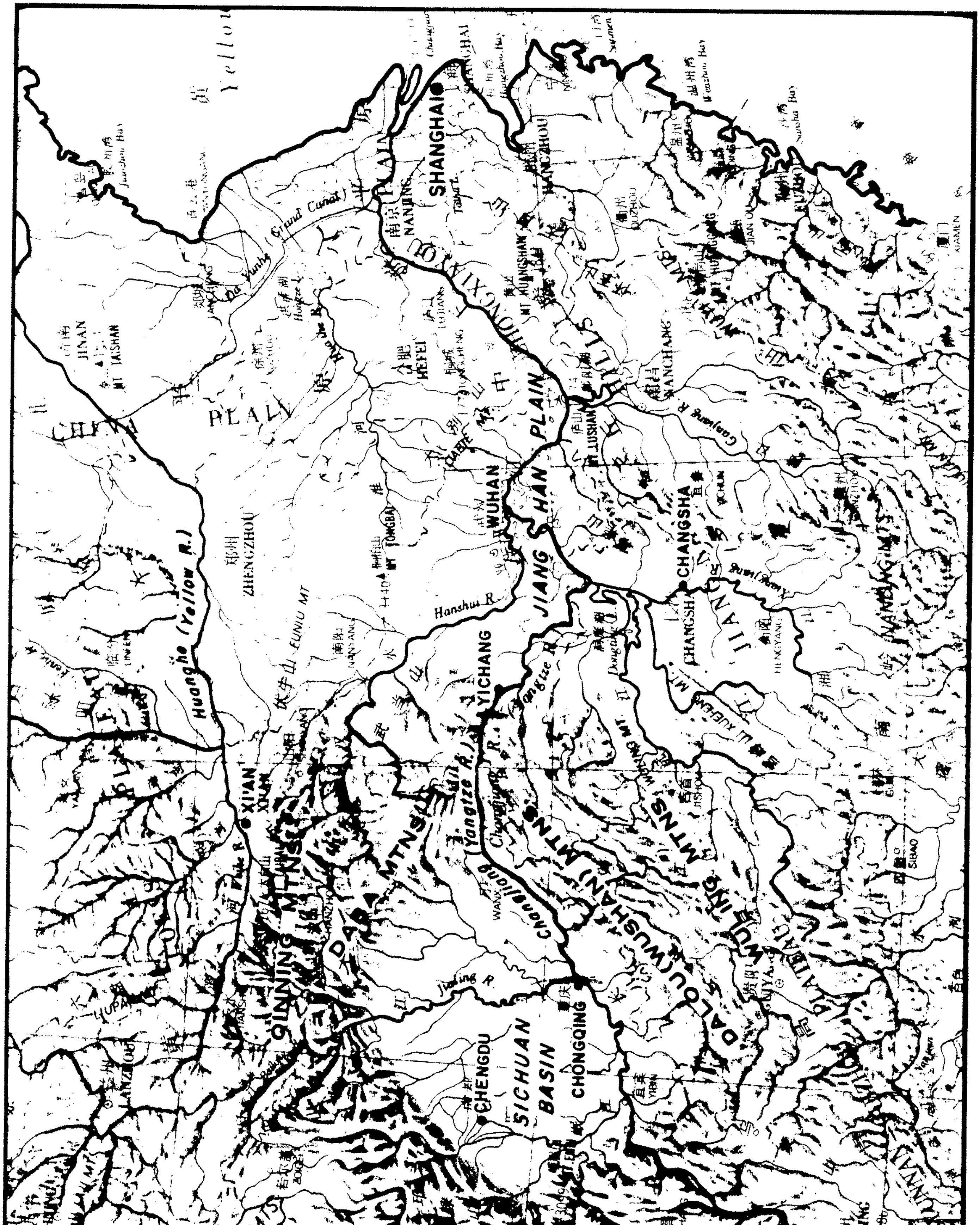
The principal reference for project geology is Volume 3 of the 1985 Preliminary Design Report (YVPO, 1985) but a number of other sources have been consulted as noted in the bibliography.

### 3.1.2 Regional Geology

In the project region between Chongqing and Yichang the Yangtze River traverses the hilly to mountainous area that is at the junction of the converging Daba and Dalou hill ranges **(Figure 3.1)**. These ridges are formed of folded Palaeozoic and Mesozoic sedimentary formations that overlie a Precambrian basement complex of igneous and metamorphic rocks. A simplified version of the regional geology is shown in **Plate 4.4. Table 3.1** summarizes the main geological units and tectonic events.

The Precambrian basement complex is exposed in two zones near the western edge of the project region. The southernmost of these zones is the Huangling Anticline, a north–south trending arch structure in the basement rocks that has been exposed by erosion of younger sedimentary formations. The Three Gorges damsite at Sandouping is located in the Precambrian granitic rocks near the southern edge of the Huangling Anticline.

The basement rocks at the damsite are part of the Yangtze Platform, a continental plate element that extends under the sedimentary cover of the reservoir area and the adjacent Sichuan basin. The Yangtze platform is believed to have been formed by the agglomeration of several masses of primitive continental crust, largely of granitic composition. Since late Precambrian time it has existed in its present form, a stable, peneplained, crystalline massif bordered by weaker mobile crustal zones that have been




PHYSIOGRAPHIC FEATURES OF YANGTZE BASIN




FIGURE 3.1

**TABLE 3.1 - DAMSITE AND RESERVOIR AREAS - PRINCIPAL GEOLOGIC UNITS AND EVENTS**

| ERA | PERIOD | ISOTOPIC AGE (MYBP)[1] | TECTONIC STAGES | MAIN EVENTS | TYPICAL FORMATIONS |
|---|---|---|---|---|---|
| Cenozoic | Quaternary | 1 | Himalayan | - Uplift of Qinghai-Tibet Plateau; formation of Yangtze River | Alluvial terraces (QAL) |
| | Tertiary | 65 | | Erosion of highlands and deposition of molasse sediments in graben basin east of Huangling antiform. | |
| Mesozoic | Cretaceous | 137 | Yanshanian | Uplift, folding, faulting (formation of Huangling antiform and surrounding faults). | Jiakuangzhu (K1) - arkose, claystone |
| | Jurassic | 195 | Indosinian | Shallow water deposition (inland river - lacustrine clastic facies). | Ponglaizhen (J3p); Shaximiaozhu (J2s) Xingtiangou (J2x); Zengjuzhong (J1z) Xujiahe (T3xj); Badong (T2b) - red sandstone, mudstone, claystone |
| | Triassic | 230 | | | Leikoupo (T21); Jialingjiang (T1j) Dayei (Tid); Feixinguan (Tif) - limestone, marl, shale - |
| Palaeozoic | Permian | 280 | Hercynian | Epicontinental sea deposition (marine carbonate - clastic facies). | Permian (P2, P1) limestone, shale, coal seams - |
| | Carboniferous | 350 | | | Carboniforous (C2) and Devonian (D3) - Dolomite, sandstone, shale - |
| | Devonian | 400 | Caledonian | | silurian (S2, S1) - siltstone, sandstone, shale - |
| | Silurian | 440 | | | |
| | Ordovician | 500 | | | Ordovician (O3,O2,O1)- limestone, shale |
| | Cambrian | 600 | | | Cambrian (C3,C2,C1) dolomite, limestone, shale. |
| PRECAMBRIAN: Proterozoic | Sinian | 850 | Jinningian | Transgressive phase to marine environment. | Sinian (Zb) - limestone, dolomite, shale |
| | | 1 850 | Liuliangian | Major unconformity (erosion) | |
| PRECAMBRIAN: Archaen | | 2 600 | | Formation of Yangtze platform (coalescence of igneous, metamorphic terranes). | Granite, schist, diorite. |

NOTE: 1. MYBP = million years before present.

the sites of mountain building and tectonic activity. To this day the Yangtze Platform remains a stable base on which younger sedimentary formations have accumulated and been deformed.

From late Proterozoic Sinian time, 850 million years before present (MYBP), through the end of the Triassic (200 MYBP) shallow seas covered the Yangtze Platform and a thick marine sequence of carbonate and clastic sediments was accumulated. The resulting limestone, shale and sandstone formations are now exposed in the downstream half of the project region between Fengjie and Yichang.

In late Triassic time the Yangtze Platform and the North China continental crustal plates drifted together forming the Qinling mountains on the northern border of the project area and leading to partial emergence above sea level of the Yangtze Platform area. In subsequent Jurassic and Cretaceous periods a shallow water, fluvio–lacustrine environment prevailed and mainly clastic sediments were deposited, including red beds and some evaporite deposits. These younger rocks are widely distributed in the upstream part of the project area.

Tectonic activity around its margins had little effect on the strong, crystalline core of the Yangtze Platform but did cause deformation of the younger sedimentary cover. Most folding and faulting of the sedimentary rocks in the project region took place in Jurassic and Cretaceous time (150–75 MYBP) in connection with the Yanshan orogenic period.

Following the Cretaceous the land surface in the project region continued to emerge and continental conditions prevailed with the erosion of highlands, progressive development of drainage systems and deposition of alluvial materials in adjacent basins. Commencing in the Pliocene (5–10 MYBP) this tendency was accentuated by further up lift associated with the Himalayan orogeny. Progressive uplift, that continues to the present day, of the Himalayan mountains and Qinghai–Tibetan plateau created an easterly flowing drainage system and led to the formation of the modern Yangtze river valley. The youngest geological deposits in the project area are those associated with the formation of the river valley: Quarternary alluvial terraces and recent slope wash, landslide and alluvial materials, including sediments deposited since 1981 in the forebay of Gezhouba reservoir.

The main features of the damsite and reservoir geology can be summarized in the light of the preceding historical overview. The damsite is located in Precambrian crystalline basement rocks of the Huangling anticline. These rocks extend over a 35 km long reach of the river (Meirentuo reach). The crystalline rocks weather to gentle slopes and the river valley is broad. Upstream and downstream of the Huangling anticline the river cuts the oldest sedimentary rocks, folded limestones, sandstones and shales of marine origin. The topography is rugged with steep river banks extending more than 1000 m above the valley bottom and numerous landslides. Where the river has cut through massive limestone and sandstone formations a number of deep, steep–walled canyons have formed. These are the Three Gorges from which the region and the project take their name.

Further upstream progressively younger rocks are encountered and above the city of Fengjie the river runs in gently folded Jurassic and Triassic sandstones and shales. The valley is more open with rolling hills and moderate slopes.

### 3.1.3 Tectonics and Seismicity

Underlain by the stable Precambrian rocks of the Yangtze Platform the project region is one of low tectonic and seismic activity. As shown on **Plate 4.5,** large historic earthquakes ($M = 6.5$) are associated with active fault systems located over 200 km to the north and southeast of the site around the margins of the Platform.

Two groups of large scale faults occur in the project region. The first group includes Jiuwanxi, Xiannushan, Tianyanping, Banmiao and Yuanan faults that surround the Huangling anticline. These are wrench or gravity faults that were formed in the sedimentary strata during the Yanshan period of folding. Their development is believed to be directly related to the presence of the dome of crystalline rock that concentrated regional stresses in a concentric pattern.

The second group of faults is located west of the damsite in the hills bordering the reservoir. These are thrust faults that parallel the folds and were formed with the folds during the Yanshan orogeny.

A number of historical earthquakes up to magnitude $Ms = 5.5$ have been located along these fault lines and detailed ground surveys, including long–term monitoring instruments, show some small scale displacements are still occurring. It seems likely that such activity is the result of crustal readjustments associated with the slow, ongoing uplift in the Himalayan region of Western China.

Future activity, including the possibility of reservoir induced seismicity will be limited by the length of the existing fault segments that do not exceed 30 km. These considerations are discussed in more detail in Section 4 but seismicity is not considered a feasibility issue for the project.

## 3.2 Explorations

Until 1980 the exploration work was divided between studies of regional and reservoir geology and seismicity and comparisons of alternative sites for the dam. A total of 14 axes were investigated in the section of the river between the mouth of the Three Gorges near Yichang and the village of Miaohe located 56 km upstream. Four axes were located in the limestone canyons in the downstream reach of this section and ten axes are in the adjoining granitic rocks of the Huangling anticline. The work covered a range of project alternatives with reservoir levels up to El 220 and included geological mapping at 1:100 000, 1:25 000 and 1:10 000 scales and 67 000 m of exploratory drilling, as well as a variety of special studies and tests.

From 1980 the investigations have been concentrated on the selected axis located in the granitic rocks near the village of Sandouping. Investigations for the Sandouping damsite and the related reservoir studies are summarized in **Table 3.2.** Locations of the work are shown on **Plate 4.7.**

The quantity of foundation investigations at Sandouping surpasses by a wide margin normal feasibility requirements, particularly given the relatively homogeneous nature and good quality of the bedrock, and detailed investigations are still continuing to provide additional design information. This level of detail is justified by the exceptional scale and importance of the project and the need to anticipate all geological conditions that could cause unusual delays or expenses.

Most of the site explorations are conventional including core drilling and water pressure testing, excavation of exploratory adits, seismic refraction surveys and detailed geological mapping. One additional technique that is noteworthy is the use of large diameter (1.0 m) calix borings to depths of around 50 m to investigate the distribution and continuity of low angle joints and shears in the foundation rocks. The large diameter cores from

# TABLE 3.2 – SUMMARY OF GEOLOGICAL EXPLORATIONS

## A: GEOLOGICAL MAPPING

| | |
|---|---|
| – Regional and Reservoir Area – 1:50 000 to 1:500 000: | 23 100 $km^2$ |
| – 1:10 000: | 160 $km^2$ |
| – Alternative Axes – various scales 1:1000 to 1:25 000: | 461 $km^2$ |
| – Sandouping Site – 1:1 000, 1:2 000: | 8.2 $km^2$ |

## B: DRILLING, ADITS, SHAFTS, TEST PITS (SANDOUPING SITE)

| | |
|---|---|
| – Core drilling (NX) | 1 091 holes,86 445 m |
| – Calix drilling (1.0 median) | 9 holes, 356 m |
| – Adits | 9 adits, 1 260 m |
| – Shafts | 7 shafts, 247 m |
| – Pits and trenches | 17 544 $m^3$ |
| – Water pressure tents in drill holes | 4 913 sections |
| – Pumping tests | 42 tests |

## C: GEOPHYSICS (SANDOUPING SITE)

| | |
|---|---|
| – Seismic refraction | 120 km |
| – Electrical resistivity | 1 765 points |
| – Drill hole logging | 183 holes, 23 188 m |

## D: ROCK MECHANICS TESTING: (SANDOUPING SITE)

| | |
|---|---|
| – Physical properties | 996 |
| – Compressive strength | 2 298 |
| – Rock shear tests – in–situ | 78 |
| – laboratory | 85 |
| – Deformation modulus – in–situ | 36 |
| – laboratory | 469 |
| – Sonic velocity/dynamic modulus (in–situ) | 1 100 |
| – In–situ stress determinations | 2 |

## E: CONSTRUCTION MATERIALS INVESTIGATIONS

| | |
|---|---|
| – Bore holes | 325 holes, 4 931 m |
| – Test pits | 250 pits, 2 274 $m^3$ |
| – Exploratory shafts (caissons) | 24 caissons, 418 $m^3$ |
| – Classification tests | 1 306 |
| – Seismic refraction | 226 km |
| – Electrical resistivity | 2 289 points |

these holes remain a source of interest to all visitors to the site. Extensive drilling of structure foundations in the bed of the river has been performed from large drilling barges.

## 3.3 Site Geology

### 3.3.1 General

The Sandouping site is located at a bend in the river, 40 km upstream from Yichang. Maoping Creek joins the Yangtze on the right bank immediately upstream of the axis and an island, Zhongbao Island, lies on the axis near the right bank. The entire damsite area is underlain by Precambrian granitic and metamorphic rocks. At the present river level, controlled around El 66 by the downstream Gezhouba Project, the river valley is 1 100 m wide. The valley profile has three sections. The main river channel in the centre of the valley is "vee" shaped descending from El 40, where it is 150 m wide, to near sea level. This channel is flanked by broad rocky flood plains that are now permanently flooded to El 66 by the Gezhouba Project reservoir. Above this controlled water surface the valley sides rise at gentle slopes of 10 to 30 degrees, typical of weathered granite, to around El 300. The right abutment is somewhat steeper than the left. In the distance steep cliffs of younger limestone formations rise above the granites to El 1 600.

The main features of the site geology are shown on **Plates 4.8 and 4.9.**

### 3.3.2 Overburden

Overburden materials comprise residual soils, alluvium and scattered pockets of terrace alluvium above river level. Alluvial materials cover much of the river bed. They are thin except in the bottom of the main river channel where there is 8 to 10 metres of sand and gravel and around Zhongbao Island where up to 8 m of fine silty sands have accumulated since the creation of Gezhouba Reservoir.

Zhongbao Island is rock controlled but is partly covered with older flood plain sediments, mainly composed of fine sand, silt and clay, that are several thousand years old as shown by the presence of neolithic artifacts.

There are also several mounds of boulders from one to four metres in diameter near Zhongbao Island and on the flood plains on the left side of the river. These are all fresh granite blocks that have accumulated in–situ through the erosion by the river of surrounding weathered granite material.

### 3.3.3 Bedrock Lithology

Bedrock at the damsite consists of grey granite that contains some enclaves of diorite and schist and is cut by a number of younger pegmatite and diabase dykes. In the area of the damsite the granite is predominantly medium to coarse grained and is composed of quartz (25%), plagioclose (55%), biotite mica (10–15%) and hornblende (10%).
Rock mechanics testing shows uniaxial compressive strengths for wet samples of fresh rock of 100 MPa or greater. The deformation modulus, as determined in the laboratory on intact specimens of rock ranges from 50 000 to 100 000 MPa. A number of in–situ determinations using a plate jacking method in partly weathered rock gave lower values from 15 000 to 45 000 MPa.

### 3.3.4 Structural Geology

With the detailed information available from site mapping, adits and borings, exhaustive statistics have been compiled on the distribution and orientation of structural elements like joints and faults. The locations of the most prominent faults and shear zones are shown on **Plate 4.8.** Detailed descriptions and statistical data are in YVPO reports.

The foundation rocks have been affected by several periods of tectonism but the basic structure is considered to have been imprinted in Precambrian time, during the formation of the Yangtze platform.

The most prominent structural elements are steeply dipping shear and fault zones that are of two main orientations, one trending NNW and dipping SW 60–75 , the other striking NNE and dipping NW 60–65 . These zones are all narrow, ranging in width from a few centimetres to a few metres, and are generally reconsolidated into hard, intact rock material. Only one significant case was observed of weak rock material being associated with a fault or shear zone. This is in adit No. 3008 where a northeasterly trending fault zone contains one to three metres of soft mylonite and gouge. This zone is associated with a diabase dyke. The absence of any east–west trending weakness zone in the main river channel has been demonstrated by inclined, overlapping borings drilled from each bank.

Joints in the rock mass follow the same pattern as the steep faults and shears. The most common sets are oriented NNE and NNW and are steeply dipping. They are discontinuous with a maximum length of about 20 m. Low angle (less than 30 dip) joints and shears are few compared with the steeply dipping features described above, but have been sought out carefully because of their potential to affect foundation seepage and dam stability. Low angle shears have been identified in both abutments and near the centre of the valley but their distribution seems fairly random. From exposures in adits and correlation of large diameter borings the low angle features are short and discontinuous, being frequently offset along intersecting steep shear planes.

### 3.3.5 Rock Weathering

Rocks in the damsite area display a weathering profile that is typical for granitic rocks in a humid, subtropical climate. The weathering process involves a combination of leaching of silica by ground waters rich in organic acids and oxidation of the mineral components. The weathering profile grades from completely decomposed rock through zones of partly decomposed material with spheroidal masses of intact rock and partially weathered jointed rock to the fresh rock material.

The completely weathered rock is a coarse, sandy slightly cohesive mass of mineral grains that can be excavated readily without blasting. The transitions from completely weathered material to the partly weathered jointed rock mass and to unweathered material are gradational in nature and can vary several metres in depth over a short distance.

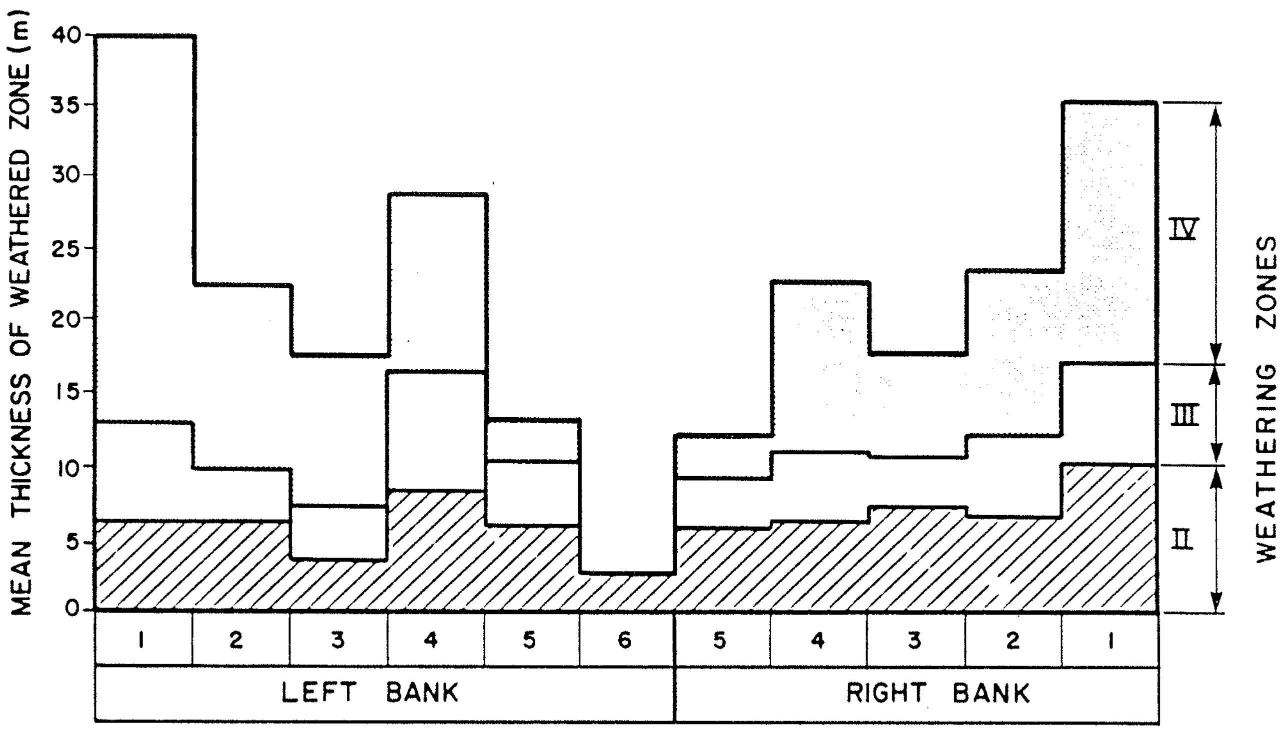
The weathering follows joints and microfissures in the rock so the extent of weathering depends both on topography and on rock structural features, ridge or plateau forms and closely fractured rock masses being most susceptible. **Figure 3.2** shows the depth of weathering in different areas of the damsite as a function of site topography while, as indicated on **Plate 4.8,** deeply weathered zones in the riverbed are associated with intersecting shear and fault zones.

In YVPO studies the weathered rock material is classified according to a system widely used in China into four or five zones; completely weathered, strongly weathered, weakly weathered (may be subdivided into upper and lower zones) and slightly weathered.

In practice this classification is applied subjectively according to physical appearance as well as records of core recovery and permeability testing in drill holes. **Table 3.3** summarizes the main criteria used and the corresponding physical properties of the various zones. The classification system is important since it is used to estimate the quantity of materials that can be excavated by mechanical means, the "completely weathered" zone, and those that must be blasted, generally all others. It has also been used by YVPO to define excavation limits for structure foundations.

## 3.4 Engineering Geology

The extensive explorations completed at the damsite demonstrate conclusively the excellent quality of the granitic foundation rocks. They have also provided an exceptionally complete data base for the assessment of all significant design issues. These include questions of excavation limits and related foundation treatment requirements, excavation slopes and support requirements for the deep navigation locks and approach channel, assessment of foundation strength parameters relative to dam stability and the evaluation of construction material sources.




LEGEND

WEATHERING ZONES : IV Completely Weathered Zone
III Strongly Weathered Zone
II Weakly Weathered Zone

TOPOGRAPHIC ZONES : 1. Ridges
2. Hillsides
3. Gully
4. First Terrace
5. Flood Lands
6. River Bed

## ROCK WEATHERING VS SITE TOPOGRAPHY

Volume 4
FIGURE 3.2

## TABLE 3.3 - ROCK WEATHERING CHARACTERISTICS

| WEATHERING ZONE | | DESCRIPTION | CORE RECOVERY (%) | RQD (%) | JOINT DENSITY (No/m) | SEISMIC (P-WAVE) VELOCITY (km/s) | PERMEABILITY cm/s(1) | WET COMPRESSIVE STRENGTH (MPa) |
|---|---|---|---|---|---|---|---|---|
| Completely Weathered | | - Yellow-brown, cohesive mass of sand & gravel size particles.<br>- Disintegrates to sand in core drilling.<br>- Requires full support in adits.<br>- Can be excavated by hand tools. | 0-5 | 0 | - | 0.66(2) / 0.5-1.0 | $1x10^{-4}$ to $3x10^{-3}$ cm/s max: $7x10^{-3}$ cm/s | 0.4-2.0 |
| Strongly Weathered | | - Yellow-brown, irregularly hard mass of sand and gravel containing 20-70% spheroidal blocks of intact rock - generally 1-2 m diameter (max. 8 m diameter).<br>- Requires partial support in adits.<br>- Spheroidal masses require mechanical equipment or blasting for excavation. | 0-30 | 0-20 | - | 2.77 / 1.5-3.0 | $1x10^{-4}$ to $5x10^{-3}$ cm/s max: $1x10^{-2}$ cm/s | 0.4 (loose mat'l) 17-58 (blocks) |
| Weakly Weathered | Upper Part | - Yellow-grey, firm to semi-firm jointed rock with 4-10 cm thick alteration zone along joints including some soft, loose altered rock material.<br>- Generally no support required in adits.<br>- Blasting required for excavation. | 30-60 | 20-50 | 3 | 3.77 | 32-37% $10^{-5}$ cm/s (w 0.01) | 84.0 |
| | Lower Part | - Light brown, firm, jointed rock with 1-4 cm thick alteration zone along joints.<br>- No support required in adits.<br>- Blasting required for excavation. | 60-90 | 70-90 | 2-3 | 5.04 / 3.94-5.73 | 38-52% $10^{-5}$ cm/s (w 0.01) | |
| Slightly Weathered | | - Light grey, firm to very firm, slightly jointed rock; film of alteration only on joints.<br>- No support required in adits.<br>- Blasting required for excavation. | 90-100 | 90-95 | 1-2 | 5.39 / 4.32-5.84 | Generally $10^{-5}$ cm/s (w 0.01) | 99.0 |
| Fresh Rock | | - Light grey, massive granite with occasional joints.<br>- No support required in adits.<br>- Blasting required for excavation. | 95-100 | 90-95 | 1-2 | 5.42 | Generally $10^{-5}$ cm/s | 100.0 |

NOTE: (1) Permeability in completely and strongly weathered zones converted from [illegible] rements in m/day. (1.[illegible] m/day = 1.16 x $10^{-3}$ cm/s). In weakly and slightly weathered rock permeability based on absorption, reported as "w" in l/min/m/m. 0.01 l/min/m/m absorption is equivalent to permeability of 1 x $10^{-5}$ cm/s.

(2) $\frac{0.66}{0.5 - 1.0} = \frac{\text{average value}}{\text{range of values}}$

### 3.4.1 Depth of Excavation

YVPO have defined the proposed excavation limits in terms of the weathering classifications for the granite foundations. In all previous studies the excavation for the foundation of most of the dam and permanent structures has been taken to the top of the slightly weathered rock, which by definition is both strong and impervious and will readily satisfy the national design code for concrete gravity dams (SDJ 21–78).

Much of the overlying "rock" materials – weakly weathered and strongly weathered zones – have strength and permeability characteristics that are normally satisfactory as a dam foundation or can be readily treated by conventional means, such as grouting or excavation and dental concrete. For feasibility assessment purposes CYJV considers that excavation to a general foundation elevation at the top of the weakly weathered zone represents a reasonable assumption. Any pockets of overly weak or pervious rock which may become apparent during stripping of the foundations will be removed as part of normal construction practice.

### 3.4.2 Excavation Slopes and Support Requirements

Excavation slopes proposed by YVPO for the navigation locks and approach channels are designed according to the weathering characteristics of the granite. For concrete lined sections essentially vertical cuts are proposed in the fresh granite while for unlined slopes the overall slope angle is 72 in fresh, slightly and weakly weathered zone and 45 in the strongly and completely weathered material. CYJV considers these slopes to be appropriate for feasibility purposes but recommends the addition of a protective berm at the base of the completely weathered rock.

Rock anchors will only be required locally to support the unlined rock slopes.

### 3.4.3 Rock Properties for Dam Stability

In–situ testing of slightly weathered and weakly weathered rock in the dam area shows that values of the parameters f (friction coefficient) and c (cohesion) for the concrete/ rock interface are generally above $f=1.1$ and $c=1.5$ MPa respectively. The corresponding figures for the rock/rock interface are 1.5 and 2 MPa.

Lower figures have been obtained from in–situ testing of discrete joints with relatively smooth surfaces such as the shear plane f11 in adit 3001. This plane is a unique phenomenon of limited extent whose continuity is interrupted by a series of intersecting joints. Also, adit No. 9 which is currently being excavated at a steep incline in the left abutment area clearly demonstrates the absence of low angle weakness planes that could affect stability of the dam blocks resting above.

It is, therefore, realistic to check stability with sliding planes in the rock using values of typically rough irregular joint surfaces with the understanding that there is always a possibility of some local combination of features that may require special attention during construction.

### 3.5 Construction Materials

The main material requirements for the construction of diversion works and permanent project structures are as follows:

| ITEM | QUANTITY ($m^3$ X $10^6$) |
|---|---|
| – Impervious fill | 2.2 |
| – Processed granular fill (filters & transitions) | 2.5 |
| – Random granular fill | 8.5 |
| – Rockfill | 21.0 |
| – Coarse aggregate | 29.0 |
| – Fine aggregates | 8.0 |

Granite rockfill and weathered sand from completely decomposed granitic bedrock will be produced in very large quantities from site excavations. Quarry sources for concrete aggregates are also located near the dam site.

Impervious material such as silty clay is available in only limited quantities around the dam site and there are no significant deposits of natural granular materials such as sand and gravel. For these materials the nearest sources which meet project requirements are located along the Yangtze 60 km downstream from Sandouping.

The locations of potential borrow areas are shown on **Plate 4.10.**

#### 3.5.1 Impervious Material

It is planned to use clay soils for the construction of impervious zones in the three stages of diversion works. Requirements are as follows:

| Diversion Stage | Clay Required ($m^3$ x $10^3$) |
|---|---|
| Stage I | 300 |
| Stage II | 700 |
| Stage III | 1 200 |
| TOTAL | 2 200 |

Suitable materials have been found in river flood plain and terrace deposits. The available quantities and material characteristics are summarized in **Table 3.4.**

TABLE 3.4 - IMPERVIOUS MATERIAL - BORROW AREAS

| Burrow Area Number | Name | Available Clay Quantities | Distance from Site | Liquid Limit | Plasticity Index | USC** |
|---|---|---|---|---|---|---|
| | | $m^3 \times 10^3$ | km | % | % | |
| 1 | Wuxiangmiao Lujiahe | 573 | 4.0-4.5 | 12.1-12.1 | 28.2-38.9 | CL |
| 2 | Maoping | 1 025 | 1.0-2.0 | 26.6-36.1 | 9.7-15.1 | CL |
| 3 | Zhongbao | 38 | 0 | | | |
| 4* | Xujiachong | 140 | 2.5 | 28.6-32.9 | 10.6-15.9 | CL |
| 5* | Chenjiachong | 62 | 3.0 | 31.4-33.9 | 12.1-14.9 | CL |
| 6* | Bahekou | 61 | 6.0 | | | |
| 7* | Bimuoze and Yongjiawen | 672 | 3.0-5.5 | | | |
| 8 | Goloubai | 18 780 | 66 | 36-44 | 14-21 | CL |
| 9 | Hunghuatau | 10 830 | 68 | 32-44 | 12-19 | CL |
| 10 | Yagieling | 12 650 | 71.5 | 57.3 | 24.3 | MH |

*Not available for construction
**Unified Soil Classification System

There is not enough material available in the immediate vicinity of the damsite to satisfy all the requirements so some material must come from the downstream deposits. Also, the principle impervious source in the damsite area, the Maoping borrow area, both has a natural moisture content in excess of optimum and will be subject to flooding after completion of the Stage II Cofferdams. Thus, the development of the Maoping borrow area must be carefully planned if its potential as an inexpensive local source is to be realized.

Clays from borrow areas 8 and 9, located downstream from Gezhouba, are medium plastic clays of slightly higher plasticity than clays from the damsite area. They are expected to be more impervious than clays from the damsite borrow areas.

The clay from Yaqueling, borrow area 10, contains montmorillinite and is considered the only potential source near the site of material for producing slurry for cut off wall construction.

### 3.5.2 Weathered Sand

More than 20 x $10^6 m^3$ of weathered sand will be obtained from the completely weathered zone of excavations required for the dam and navigation structures. This material has a mica content in excess of 10% and cannot be used for fine concrete aggregate. However, it is planned to use over 8 x $10^6 m^3$ of weathered sand as an inexpensive source of granular fill in the construction of cofferdams for the three stages of river diversion.

### 3.5.3 Sand and Gravel

Sand and gravel for cofferdam fill and for concrete fine aggregates will come from riverbed deposits downstream of Gezhouba. The Hutatan and Huangbeihe deposits that are closest have been largely exhausted for the construction of the Gezhouba Project so most of the requirement will be obtained from the Honghuatao, Yunchi and Yidu deposits, borrow areas 2, 3 and 4.

The quantity of sand and gravel required for cofferdam construction is approximately 2.5 x $10^6 m^3$. As shown on **Plate 4.10** the available quantity is in excess of 90 x $10^6 m^3$ so there is no concern about the availability of these materials.

### 3.5.4 Concrete Aggregates

Because of the great distance to the river gravel deposits it is economical to use granite rock from damsite excavations for the production of coarse aggregates. The fact that the damsite granite contains more than 10% mica does not affect its use as a coarse aggregate, which is composed of fragments of sound, intact rock rather than individual mineral gains. For fine aggregates, however, the high mica content affects concrete strengths and the damsite granite cannot be used. Fine aggregates can be obtained from quarries where the rock properties are suitable and in the early stages of the work before quarries are developed, from the downstream river deposits.

Several rock quarry sites have been investigated including some in granite and some in limestone. The best source according to the most recent investigations is the Xiaanxi granite quarry, located 10 km downstream from the damsite on the left bank. This deposit contains over 40 x $10^6 m^3$ of granite rock that meets all test requirements for fine aggregates, including a free mica content of less than 4%. Test samples of concrete produced with this aggregate have satisfactory strength properties.

### 3.5.5 Rockfill

Rockfill is required mainly for the construction of river diversion works. The main quantities, including some provision for transitions made from crushed rock, are as follows:

| Diversion Stage | Rockfill Required ($m^3$ x $10^3$) |
|---|---|
| Stage I | 2 900 |
| Stage II | 6 200 |
| Stage III | 1 400 |
| TOTAL | 10 500 |

Rockfill can be obtained from site excavations and quarries in the area. The damsite granitic rocks will yield rockfill of excellent quality and the available quantities greatly exceed the fill requirements.

Some rockfill may also have to be obtained from quarries due to the timing of fill requirements. It is also planned to use the Shibanchi sandstone quarry in the right bank to produce large rock blocks that will be used in the final stages of river closure.

## 3.6 Summary

The damsite at Sandouping is well suited to the project requirements. It offers excellent foundations of Precambrian granitic rocks and a topography that both facilitates diversion and efficiently accommodates the permanent structures. Much of the construction material for diversion cofferdams and for concrete aggregates can be obtained economically from excavations for permanent structures.

Below the surface weathered zone the granitic foundation rocks are both strong and relatively impervious. It is considered that excavation to the top of the "weakly weathered" zone will normally provide a satisfactory foundation surface.

Faults and shear zones in the foundations are generally steeping dipping and reconsolidated. Sub–horizontal joints and shears are few and discontinuous. Shear friction values of f = 1.5 and c = 2.0 MPa are recommended for dam stability analyses within the foundation rock.

# 4. SEISMICITY

This section deals with CYJV's review of the work carried out by YVPO for assessing the seismicity of the site and determining the seismic risk to be considered in the design of the main structures.

From a preliminary review of the available documentation it was apparent that, although based on the same general principles and analytical methods as in other countries, Chinese practice with regard to the definition of seismic design parameters and performance criteria differ in some respects from approaches currently in use in the west. In these circumstances a step by step comparison of YVPO results with some other method was not possible. Instead, the CYJV review has concentrated on carrying out an independent, to the extent possible, evaluation according to accepted international practice of seismic risk and, subsequently, of the corresponding seismic stability of the main project structures.

The CYJV assessment includes first a review of the YVPO documents and, second, on the basis of the available geological and seismological data, an evaluation of seismic design parameters following the methodology recommended by the International Commission on Large Dams (ICOLD, 1983). These parameters are later used (see Section 4.9) in assessing the seismic stability of the main structures.

## 4.1 Review of YVPO Work

The following YVPO documents were reviewed:

1. YVPO (1985) Preliminary Design Report, Volume III Geology, Chapter 1 – "Regional Tectonic Stability", (includes Plate "Regional 2– Location of Earthquake Epicenters and Active Faults in the Three Gorges Region and Surrounding Area – Scale 1:1 000 000, March 1984);

2. YVPO (1985) Summary Report on Regional Tectonic Stability;

3. Catalogue of local earthquakes (1959–1986); and

4. Earthquake Resistant Design Code for Hydraulic Structures, SDJ 10–78.

### 4.1.1 Regional Tectonic Setting

As outlined in Section 3, the Three Gorges Project is located within the Central China sub–plate near the southern end of the Huangling anticline. The core of the anticline is made of crystalline rock that is exposed in the project area. At the periphery of the crystalline block, the basement rock is covered with folded and faulted sedimentary rocks where most of the seismic activity is apparently concentrated.

Investigation of the recent tectonic activity included:

- magnetic and gravimetric surveys;
- fault displacement monitoring; and
- periodic precise levelling around the site.

The magnetic surveys did not disclose any discontinuity in the basement rock and gravity gradients were found uniform without abrupt changes. Measured displacements along the faults closest to the site were very small, in the range of 0.1 mm/year, which is indicative of a very low level of activity.

### 4.1.2 Seismic Activity

Investigation of local seismic activity included:

1. the set–up and operation since 1959 of a five station micro seismic station network that has subsequently been expanded to seven stations; and

2. the study of available literature about local historical earthquakes.

The results of the investigation were presented in the form of a map of earthquake epicenters covering an area of about 200 000 $km^2$ (from longitude 108E to 113E and latitude 29N to 33N) with the site in its centre, see **Plate 4.5.** The location of the main fault systems are also shown on the map.

Several different earthquake magnitude scales are referred to in YVPO documents. Instrumental records obtained from the microseismic network or other seismograph stations have been reported in terms of local magnitude ($M_L$) on the map and in terms of surface wave magnitude ($M_S$) in the catalog. The relationship between the two scales quoted in the YVPO report is:

$$M_S = 1.13\ M_L - 1.08 \qquad (1)$$

Historical (i.e. pre–instrumental) earthquakes were assigned magnitudes deduced from felt intensities but the relationship with $M_L$ or $M_S$ is not reported. For given historic events the derived magnitudes are shown on the regional seismicity map in terms of M and in the report as $M_S$. They appear to have been derived from the relationship (SSB, 1987):

$$M = 0.58\ I + 1.5 \qquad (2)$$

For the present review, for the sake of uniformity, all instrumental records are presented in terms of the surface wave magnitude scale ($M_S$) while historical events are reported in terms of M.

The maximum historical earthquake in the region was one of magnitude M 6.5. There were three such events in a 2000 year period but none occurred within 200 km of the site. Instrumental data show a maximum magnitude of $M_S$ 5.1 for an earthquake which occurred near Zigui, 60 km from the site, in 1979.

The general locations of the major earthquakes agree fairly well with the most important fault zones, either mapped or inferred.

YVPO reported that about 79% of the total activity recorded by the instruments since 1959 can be associated with three minor seismic belts surrounding the Huangling anticline.

The data available about these three seismic zones are as follows:

1. The Yuanan–Zhongxiang Seismic Belt on the eastern side of the Huangling anticline:

   - percentage of total recorded activity:__________47%;
   - closest distance of the structure to the site:__________55 km;
   - maximum instrumental earthquake:__$M_S$ 4.8 (1969), in Boakang; and
   - maximum historical earthquake:_$M_S$ 5.0 (1469, 1603), in Zhongxiang (Note: YVPO also consider the Changde earthquake M 6.5 (1631) can be associated with this zone.)

2. The Xingshan–Qianjiang Seismic Belt on the western side of the Huangling anticline:

   - percentage of total recorded activity:__________22%;
   - closest distance of the structure to the site:__________50 km;
   - maximum instrumental earthquake:__$M_S$ 5.1 (1979), in Zhigui; and
   - maximum historical earthquake:__________M 5.5 (1856) in Qingjiang

3. The Zhigui–Yuyangguan Seismic Belt on the south western side of the Huangling anticline:

   - percentage of total recorded activity:__________10%;
   - closest distance of the structure to the site:__________17 km; and
   - maximum instrumental earthquake:__________$M_S$ 4.9 (1961), in Yidu

The remaining 20% of activity that cannot be associated with these three structures is distributed all around the site without special concentration.

Recorded focal depths are in the range 8–16 km, mainly in the covering strata. No earthquake with a magnitude larger than 3.0 was recorded in the core of the Huangling anticline. One main conclusion of the YVPO study is that the core of the Huangling anticline is more stable than the region around it and the seismic risk at the dam site will be governed mainly by the activity in the seismic belts surrounding the core.

#### 4.1.3 Seismic Risk Evaluation

The YVPO approach for assessment of the seismic risk at the site is mainly deterministic. For each seismic belt around the site, a maximum magnitude is assigned and the maximum intensity is then evaluated at the dam site assuming such an earthquake occurs at the point in the belt closest to the site. (Note: The attenuation relationship used to establish intensities at the damsite is not mentioned in the YVPO documents.) The maximum value of the intensity from all sources then becomes the "Basic Seismic Intensity" for the project.

The maximum magnitude assigned to the Yunnan–Zhongxiang and Xingshan–Qianjiang belts is derived from the historical data. For the Zhigui–Yuyangguan belt, it is based on the lengths of the longest individual segments of the Xiannushan and Jiuwanxi faults. The maximum length of these fault segments is reported variously in discussions with YVPO specialists and in the published reports as 15 to 30 km. Fault length – magnitude relationships used to determine a maximum magnitude ($M_S$ 5.8) for this belt include (SSB, 1987, YVPO, 1987):

$$M_S = 2.1 \text{ Log } L + 3.3 \quad (3)$$
$$M_S = 2.5 \text{ Log } L + 2.0 \quad (4)$$

The intensity values considered by YVPO for the seismic risk evaluation are:

| Seismic Belt | Assigned Maximum Magnitude ($M_S$) | Shortest Distance Between the Belt & Site (km) | Maximum Intensity at the Site |
|---|---|---|---|
| Yuanan–Zhongxiang | 6.5 | 55 | VI |
| Xingshan–Qianjiang | 6.0 | 50 | V |
| Zhigui–Yuyangguan | 5.8 | 17 | VI |

Therefore intensity VI was adopted as the "Basic Seismic Intensity" for the Three Gorges site, which completes the Chinese seismic risk evaluation. The translation of the "Basic Seismic Itensity" into design criteria is governed by the applicable design codes.

#### 4.1.4 Applicable Design Criteria (YVPO Method)

The Chinese Earthquake Resistant Design Code for hydraulic structures requires that a design intensity one degree above the "Basic Seismic Intensity" be adopted in detailed design for very large projects or for critical structures. This code stipulates also the earthquake loads should be estimated by use of a combination of factors, namely a seismic coefficient of 0.1 g (corresponding to the design intensity VII), a dynamic coefficient for high dams of 1.5 and finally an overall influence factor equal to 0.25. In addition the code requires that all compressive and temporary tensile stresses remain within the elastic range.

## 4.2 International Practice (CYJV Assessment)

This section deals with the assessment of the seismic risk at Three Gorges site according to current international evaluation methods. The resulting seismic design parameters are used in Section 9 to provide an independent check of the seismic stability of the main structures.

In this review ICOLD Bulletin No. 46 (ICOLD, 1983) is used as the reference for international practice. Its contents are largely modeled on North American practice based on USBR procedures.

To the extent that judgement is a factor in this assessment, it should be noted that CYJV have tended to choose interpretations that lead to a conservative estimate of seismic risk.

### 4.2.1 Definitions

The consensus of international opinion is that large dams should be checked for seismic stability under two loading conditions: a "worst—case" type of loading (maximum credible earthquake) and an "expected to occur during the lifetime of the structure" type of loading (design basis earthquake). The first case is for safety evaluation purposes and the second is used for economic design. Associated performance criteria vary with the loading conditions.

The definitions for these two classes of earthquake loadings may vary significantly from one organization to another, but are usually modeled on the original USBR definitions which are as follows:

1. "The Maximum Credible Earthquake (MCE) is defined as the earthquake that would cause the most severe vibratory ground motion capable of being produced at the site under the currently known tectonic framework. It is a rational and believable event which can be supported by all known geologic and seismologic data. The MCE is determined based on the maximum earthquake that a tectonic region can produce, considering the geologic evidence of past movement and the recorded seismic history of the area."

   "The dam is checked to ensure that it can withstand the loads resulting from the MCE without any sudden or uncontrolled release of the reservoir even though damage may occur. The structures, systems and components of the project critical to retention or controlled release of the reservoir are required to function during and after the MCE."

2. "The Design Basis Earthquake (DBE) is defined as the earthquake capable of producing the largest inertia forces on the dam expected to occur during its life. The DBE is primarily determined from historical magnitude versus frequency of occurrence relationships The recurrence interval for the DBE is normally defined as once in 100 years."

   "The dam is required to safely withstand the loads due to the DBE although some repairable damage is acceptable for this loading. Those systems and components important to safety must remain operable during and after the ground motions associated with the DBE."

Although these definitions are subject to periodic revision, the concepts behind the definitions remain much the same, a mainly deterministic approach for the MCE and a probabilistic approach for the DBE.

### 4.2.2 Evaluation of the MCE

Evaluation of the MCE requires a good understanding of past activity along the various fault systems around the site, together with the regional fault length/earthquake magnitude relationship derived from local experience. This type of information is not provided in the YVPO documents reviewed.

Using the seismic data provided by YVPO, it is evident that the maximum ground motion at the dam site would be generated by the closest fault system, namely the Xiannushan and Jiuwanxi faults of the Zigui–Yuyuanguan seismic belt. Despite their higher activity level, the other two seismic belts are considered less dangerous for the site because they are located at a substantially greater distance.

The maximum magnitude that could be generated along the Xiannushan and Jiuwanxi faults was estimated by YVPO to be $M_S$ 5.8 on the basis of local relationships relating magnitude and fault length. Similar relationships developed by Slemmons (1982) would predict an earthquake magnitude around $M_S$ 6.3, thus confirming the relatively low seismic potential near the Three Gorges site.

At this stage, an MCE event of magnitude $M_S$ 6.5 is selected for safety evaluation purposes. This conservative estimate reflects the complexities of the faults in the Zigui–Yuyuanguan belt and the uncertainties inherent in applying one or another of the empirical relationships between fault length and magnitude. Also, it is the same order as the maximum magnitude experienced on a more regional basis, such as the Changde event.

Based on an acceleration attenuation relationship developed in China, a $M_S$ 6.5 earthquake along the Zhigui–Yuyangguan seismic belt some 17 km distant would generate at the site a peak ground acceleration in the range of 0.15–0.20 g **(Figure 4.1)** . It should be noted that when compared with attenuation relationships in use in other countries shown on **Figure 4.2,** the Chinese relationship usually indicates lower ground accelerations.

Until more information becomes available for a full assessment of the MCE, a 0.15–0.20 g (say 0.17 g) peak ground acceleration should be considered as a starting point for safety evaluation of the main project structures.

### 4.2.3 Evaluation of the DBE

The evaluation of the DBE is based mainly on the statistical analysis of existing data, both recorded and historical.

It is important to realize that both sets of data have their own limitations. The 27–year period of recorded instrument data is too short to allow extrapolation to a very large return period. On the other hand, historical data does not usually include all events that occurred and hence reflects only the minimum level of activity to be expected.

The analysis uses the Gutenberg–Richter relationship:

$$\text{Log } N = a - bM \quad (5)$$

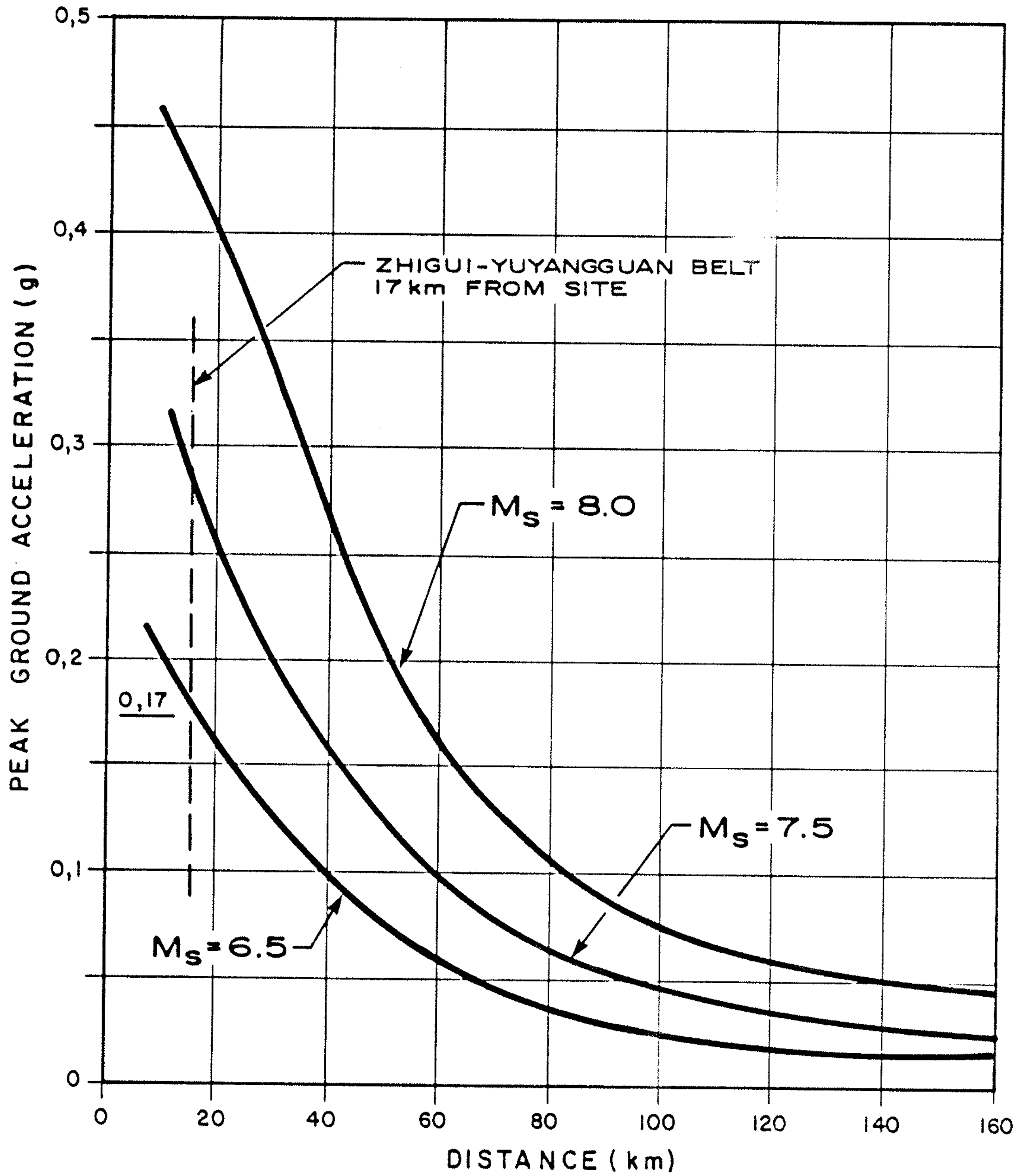
where M = reference magnitude and N = number of events larger than M.

The following Gutenberg–Richter recurrence formulae were calculated from the recorded and the historical data respectively for an area of 200 000 km$^2$:

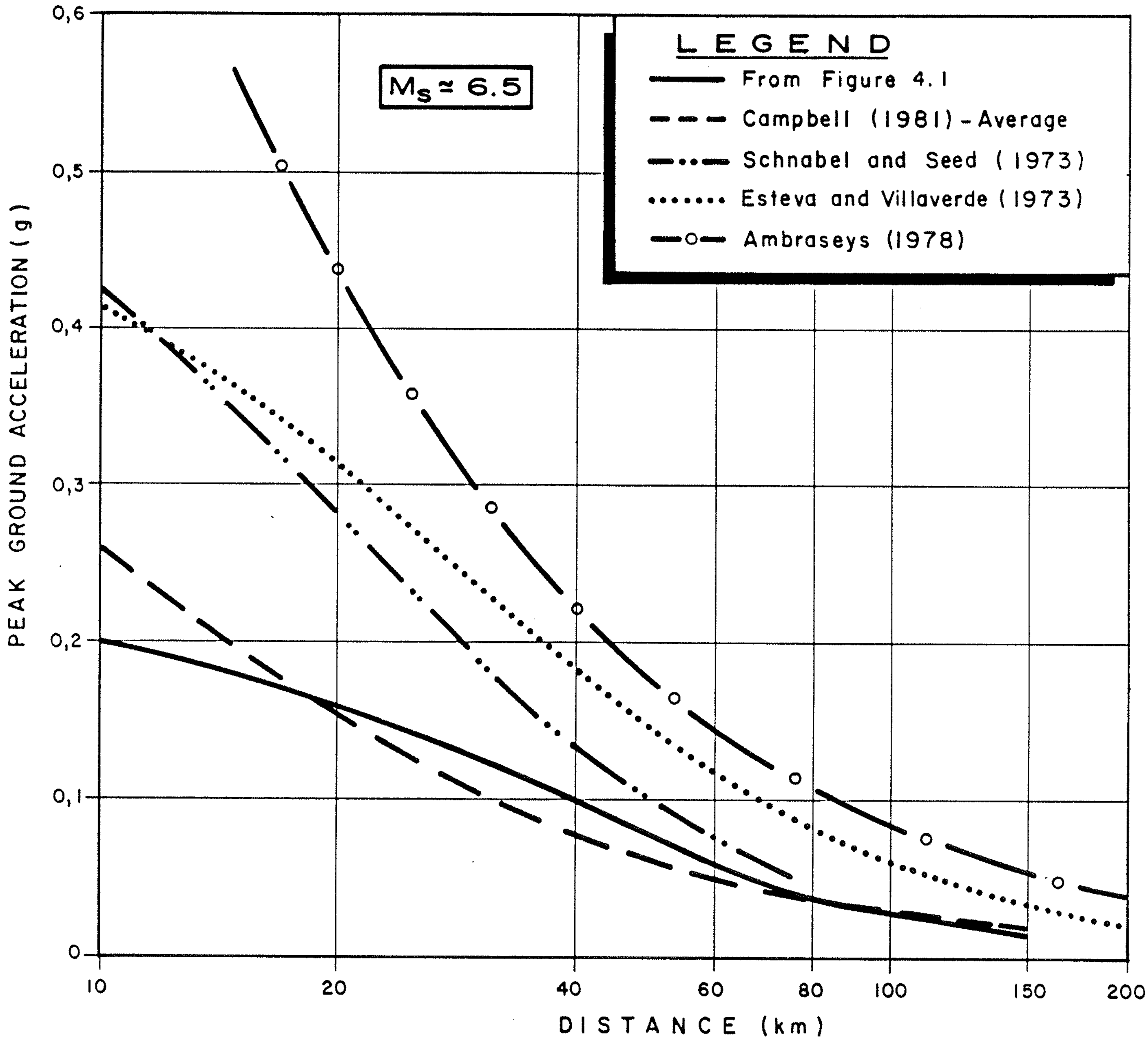
Log N = 2.17 – 0.67 $M_S$ (recorded data) **(Figure 4.3)**
Log N = 2.08 – 0.75 M (historical data) **(Figure 4.4)**
Where N = number of events per year
$M_S$ = Magnitude of the surface wave

For the historic analysis, only the period 1400–1960 was considered since the completeness of earlier records appears questionable. Also, the letter M is used instead for historical events rather than $M_S$ since the relationship between the two magnitude scales is not explicitly given in YVPO documents.

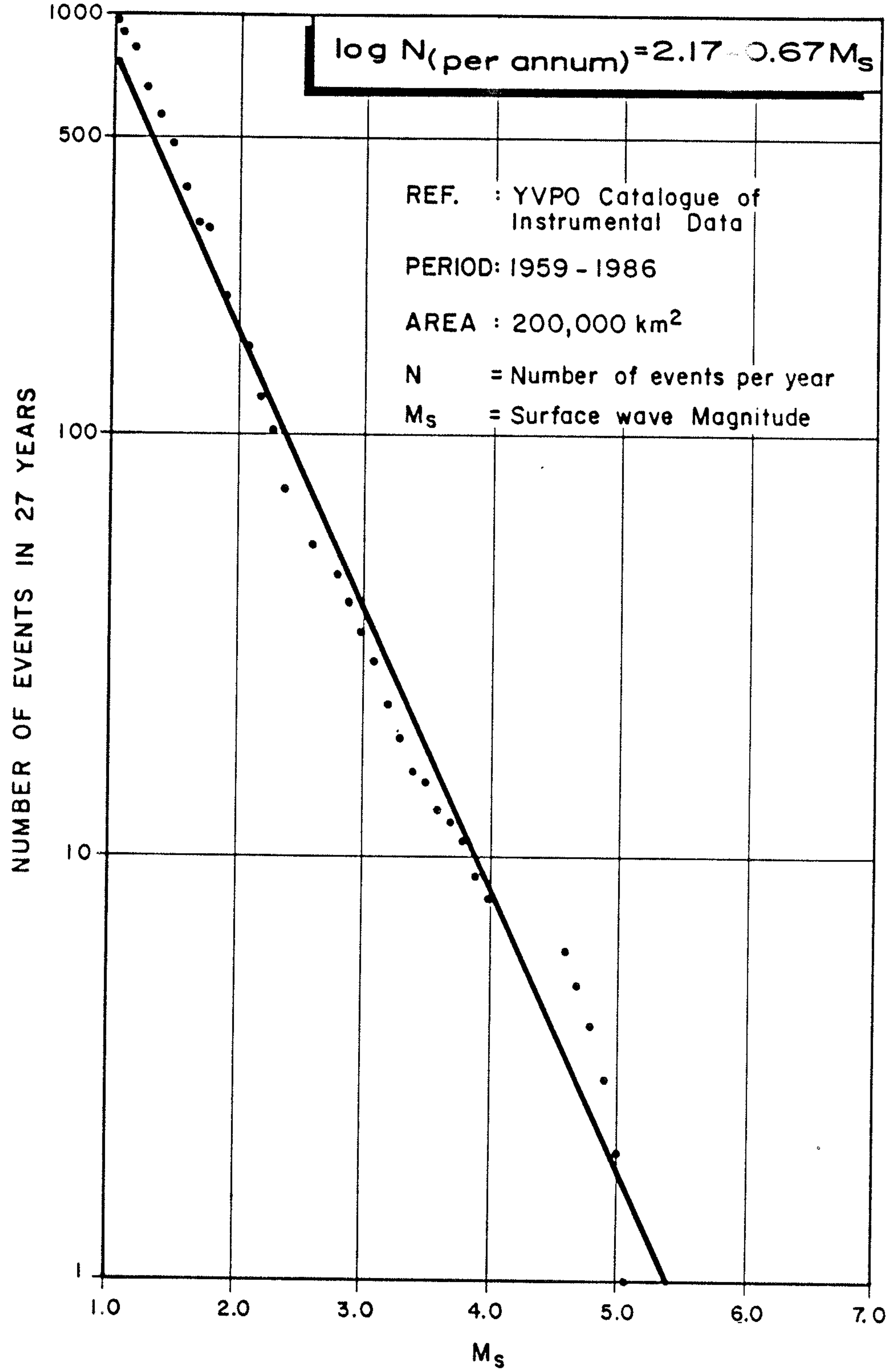
The two equations cited above are plotted on **Figure 4.4.** The differences between the two lines can be explained by the limitations of each set of data as discussed above. Moreover, there is a maximum magnitude that the local tectonic can generate; this physical upper bound naturally tends to force the curve towards a steeper slope with increasing magnitude. This would be more pronounced for historical data.




ACCELERATION ATTENUATION WITH DISTANCE RELATIONSHIP USED IN CHINA




COMPARISON OF $M_s$ 6.5 ATTENUATION RELATIONSHIPS




MAGNITUDE RECURRENCE RELATIONSHIP
FROM RECORDED DATA



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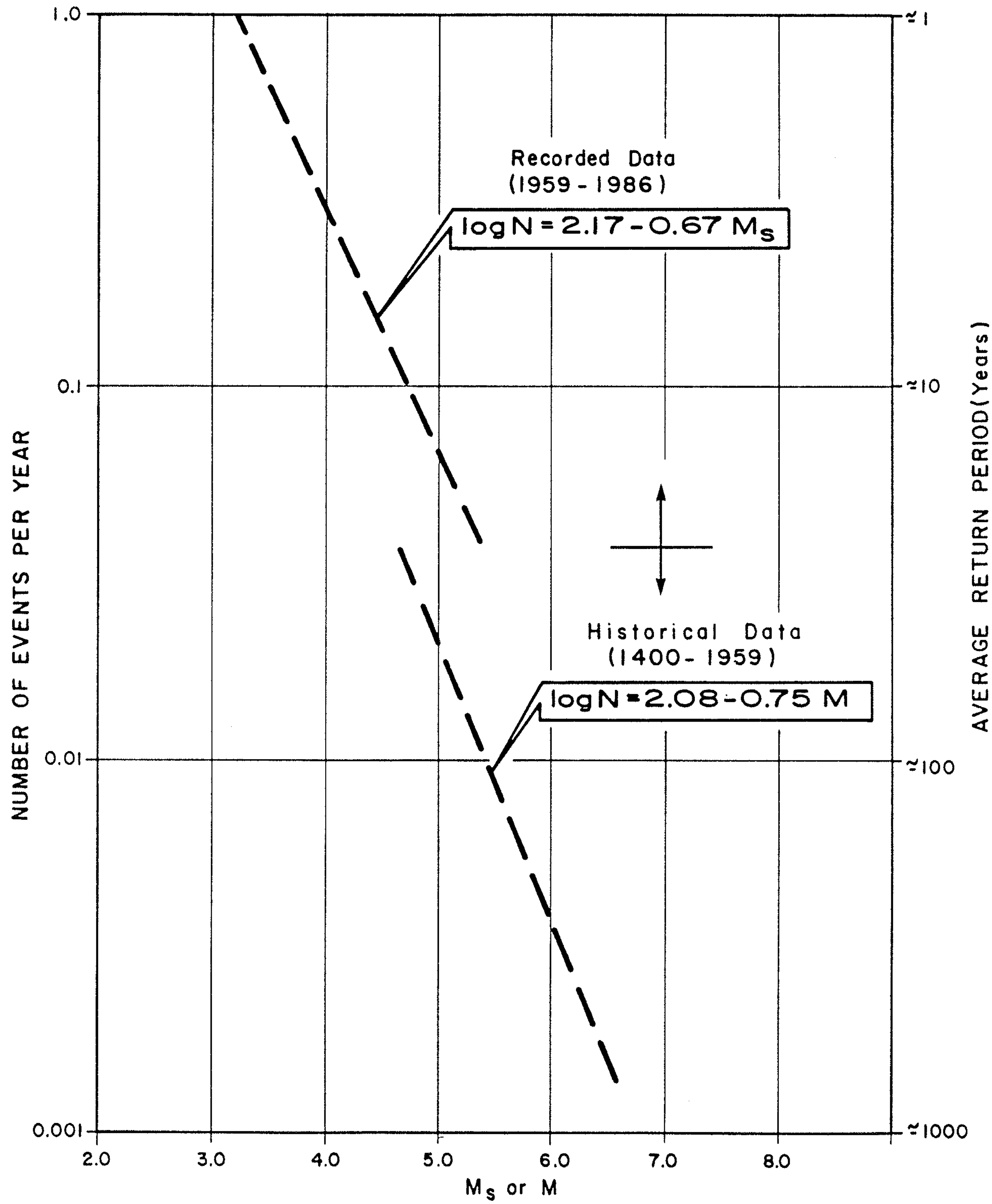
FIGURE 4.3




MAGNITUDE RECURRENCE RELATIONSHIPS
FROM RECORDED AND HISTORIC DATA

For evaluation of the DBE the curve based on the recorded magnitudes has been adopted, i.e. Log N (per annum) = 2.17 – 0.67 $M_S$. The error, if any, should be on the conservative side as the physical limit of the tectonic is not yet reflected due to the short period of record available.

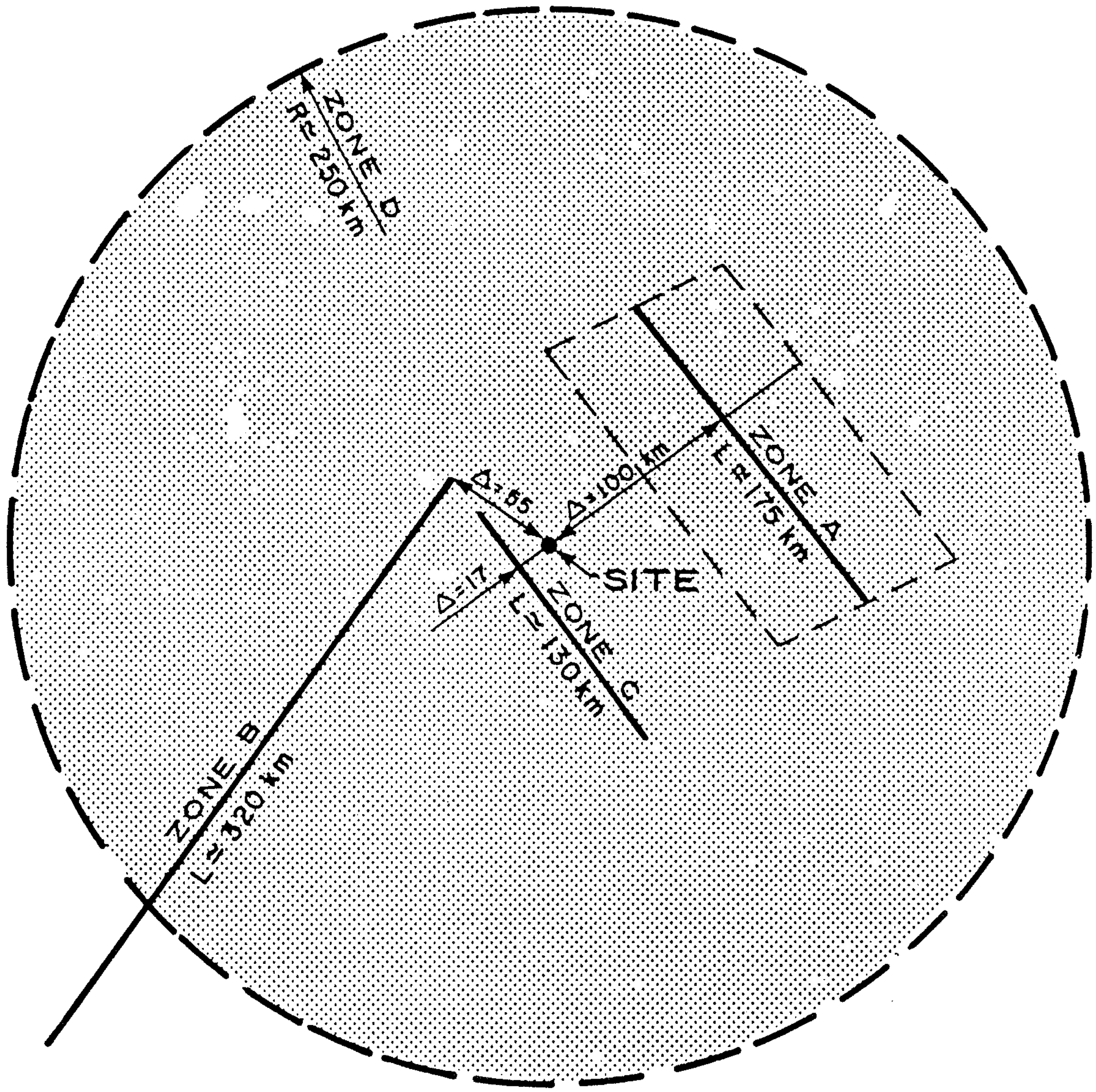
The next step is to develop two seismotectonic models. Model No. 1 distributes the seismic activity among the various elements of the model. This distribution is derived directly from the YVPO report, with 79% of the total activity being associated with the three fault systems (seismic belts) around the site. A different parameter "a" is assigned to each seismic zone in order to reflect these differences in the activity level and it is assumed that the value of "b" is a regional constant. Recurrence relationships are then determined for each of the four seismic zones.

The following data were introduced into Seismotectonic Model No. 1 **(see Figure 4.5)**.

| Zone | Total Length (Approx.) (km) | Dist. To Site (km) | % Of Total Activity | "a" Parameter Where log N ="a"–b$M_S$ |
|---|---|---|---|---|
| A (Yuanan–Zhongxiang) | 175 | 100 | 47 | 1.84 |
| B (Xingshan–Qianjiang) | 320 | 55 | 22 | 1.52 |
| C (Zhigui–Yuyangguan) | 130 | 17 | 10 | 1.17 |
| D (Background activity within 250 km from site) | | | 21 | 1.49 |

Seismotectonic Model No. 2 considered 100% of the seismic activity as being distributed in an essentially uniform and random way within a 250 km radius of the site. This model is intended only to provide a general check of the more specific approach.

The last step is the integration within each of the two models of the seismic risk over the various zones to assess the cumulative risk at the dam site. This can be done using Cornell's method (1968). To simplify the numerical evaluation, the Chinese graphical attenuation curves for peak ground acceleration versus distance are replaced by the mathematical expression of K. W. Campbell (1981) which is in close agreement **(see Figure 4.2)**.




SEISMOTECTONIC MODEL N° I




FIGURE 4.5

The seismic risk at the site in terms of peak horizontal ground acceleration versus return period is shown on **Figure 4.6** for both seismotectonic models. Model No. I yields a higher estimate for the seismic risk than Model No. 2 with uniform seismicity due to the close proximity of one of the seismic zones. The actual contribution of the various sources to the total risk are as follows (Model No. 1):

| | | |
|---|---|---|
| Zone A (Yuanan–Zhongxiang) | : | 23% |
| Zone B (Xingshan–Qiangjiang) | : | 11% |
| Zone C (Zigui–Yuyuanguan) | : | 53% |
| Zone D | : | 13% |

This results in Zone C closest to the site having the largest contribution to the total risk, although the seismic activity along this fault system is the lowest at only 10%. This is in agreement with a statement by Cornell and Vanmarcke (1969) that "the major contribution to the risk comes from the more frequent smaller earthquakes at the closer sources". This conclusion stresses the need for a careful assessment of the seismic activity along Zone C (Zhigui–Yuyangguan) fault system.

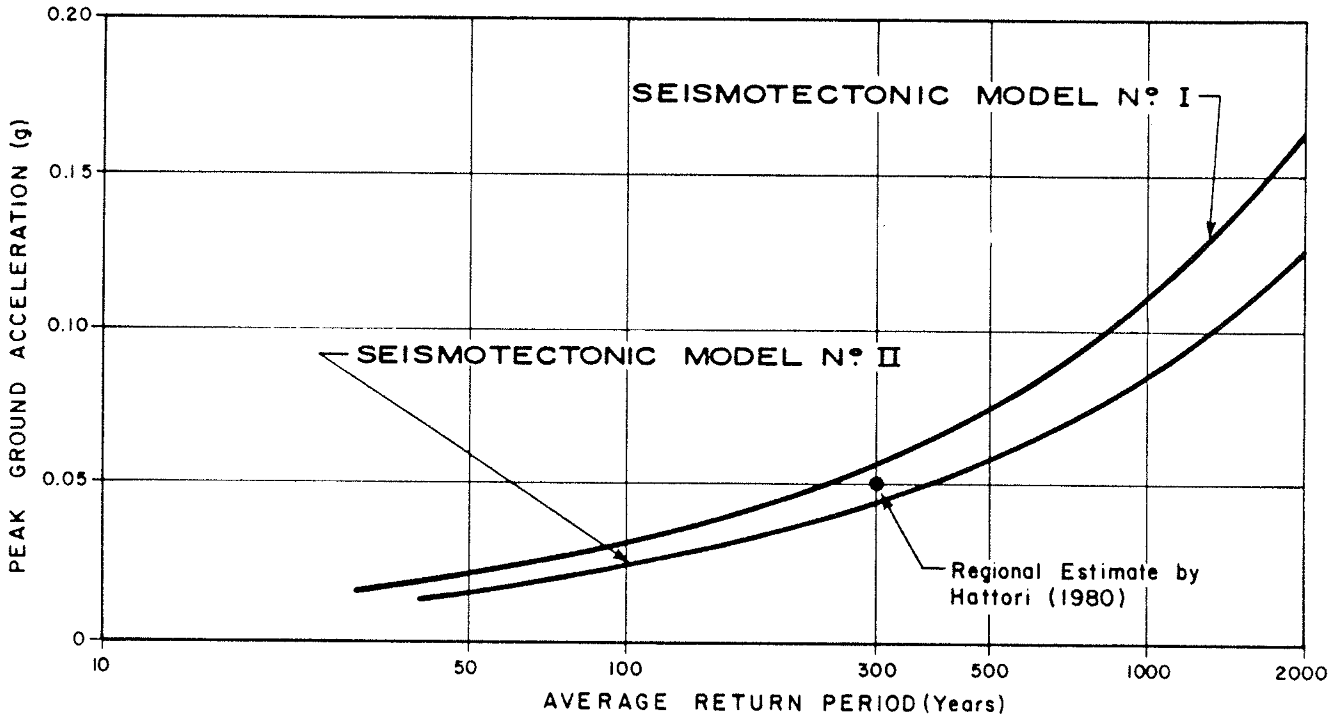
**Figure 4.6** can be used to determine the peak ground acceleration associated with the DBE, that is the earthquake having a return period of about 100 years (Section 4.2.1). This figure shows that an acceleration of about 0.03 g corresponds to a 100 year return period. However, for such a mega–project as Three Gorges it would be prudent to adopt a DBE of about 0.05 g corresponding to a return period of about 300 years. A similar estimate of acceleration versus return period (0.05 g for a 300–year period) can be read from the seismic risk map published by Hattori in 1980.

It can be observed in **Figure 4.6** that a 17% peak ground acceleration (the nominal value associated with the MCE) would correspond to a return period in excess of 2000 years at this site. This is consistent with the definition of the MCE in an area of low seismicity. However, it should be kept in mind that the accuracy of the recurrence relationship decreases rapidly for return periods exceeding the time span covered by the records used in the analysis.

## 4.3 Induced Seismicity

The intensity and consequences of reservoir induced seismicity have been reviewed. This type of earthquake activity results from reservoir induced changes in crustal stresses and in the ground water regime that cause reactivation of existing faults.

Analysis of records from the local seismograph network shows the existing level of activity along the reservoir valley to be low. Aside from the 1979 Ms = 5.1 event near Zigui there are annually very few tremors and these are small (less than Ms = 3.0). It must be considered also that the three main seismic belts are located outside the reservoir area except for short




GROUND ACCELERATION-RECURRENCE RELATIONSHIP
FOR THREE GORGES SITE

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FIGURE 4.6

stretches of fault systems "B" and "C" close to the dam site. In such areas the average seismic activity might increase slightly when the reservoir is first filled and for a few years thereafter. Further upstream the seismic activity would normally remain at the same low level.

### 4.4 Summary

The tectonic setting for the Three Gorges Project is relatively simple. The main structures will be located on the Precambrian basement rock that is exposed in the Huangling anticline while most of the seismic activity occurs in younger folded and faulted sedimentary rocks outside the core of the anticline.

It has been considered by YVPO that the most damaging seismic event for design purposes would be a $M_S$ 5.8 earthquake occurring along a fault located 17 km upstream of the dam. As a result, a "basic seismic intensity" of VI has been adopted by YVPO for the seismic design of the structures using the applicable Chinese design codes.

As an independent check of the YVPO overall design approach, seismic parameters have been deduced from available data using a methodology recommended by the International Commission on Large Dams (ICOLD). These parameters are based on the MCE and DBE concepts together with the associated performance criteria. They are used in Section 9 of Volume 4 for assessment of the seismic stability of the main project structures.

For safety evaluation purposes a horizontal peak ground acceleration of 0.17 g is recommended for use in the stress–stability analyses of the main structures for the C–1 extreme loading case (see Section 9). 9-11

With reference to the effects of reservoir impoundment, a slight increase in seismic activity is anticipated in the area upstream of the dam site where the Xingshan–Qianjiang and Zigui–Yuyuanguan fault systems cross the reservoir valley. Further upstream the seismic activity would normally remain at the same low level.